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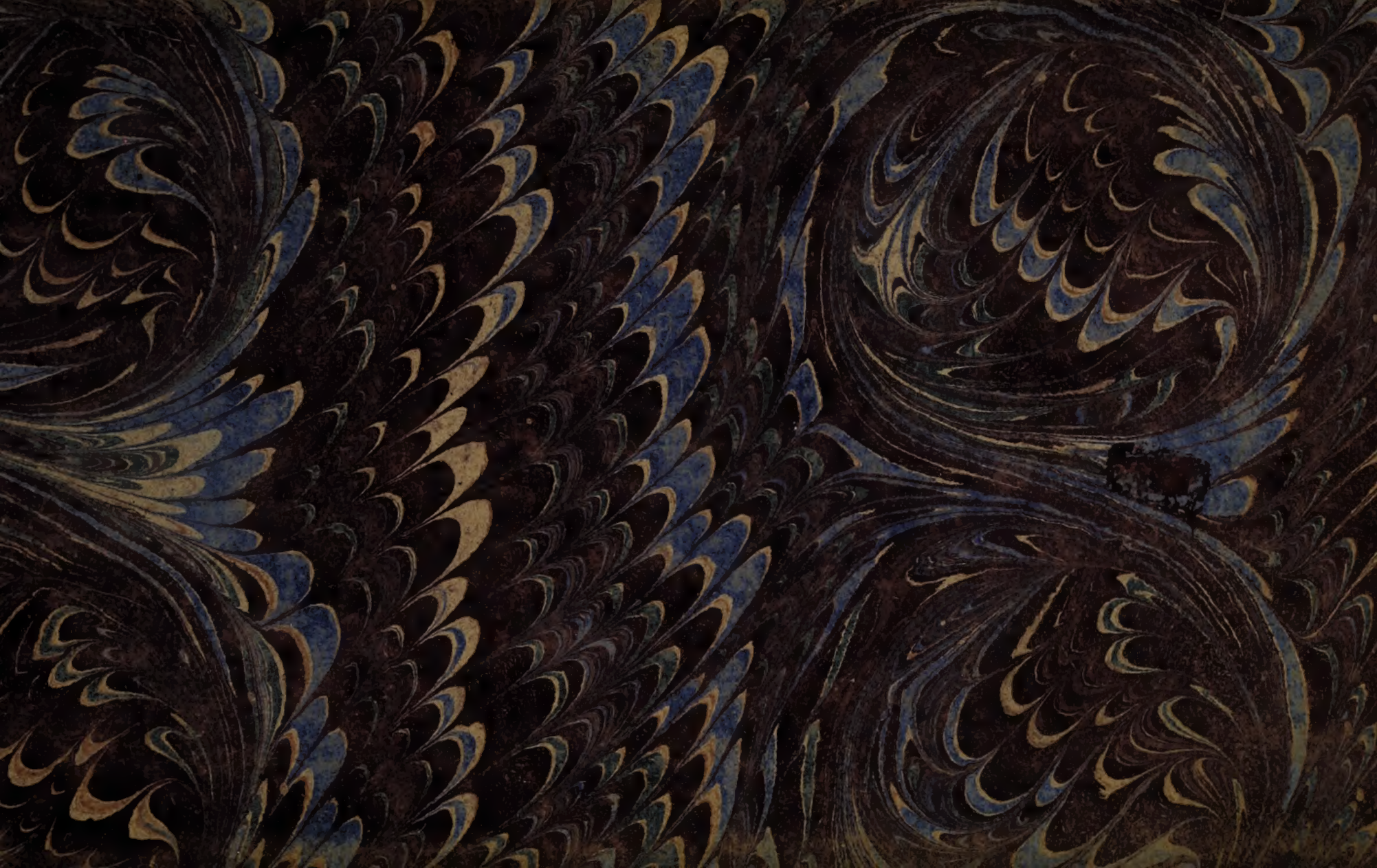

Edwd. F. Waldo.

Area of an Ellipse $= \frac{1}{4}\pi D d$

Perimeter " " " $= \pi \sqrt{\frac{D^2+d^2}{2} - \frac{(D-d)^2}{8.8}}$

R of coil with alt. cur.

$\sqrt{r^2 + p^2 l^2}$

$p = \frac{1}{2}$ alt. per sec.

l = coef. induc. = .5 to 1

r = ohmic r.

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A POCKET-BOOK

OF

ELECTRICAL RULES AND TABLES

FOR THE USE OF

Electricians and Engineers.

BY

JOHN MUNRO, C.E.,

AND

ANDREW JAMIESON, M.INST.C.E., F.R.S.E.,

Professor of Engineering, The Glasgow Technical College,
Formerly Electrician to the Eastern Telegraph Company Abroad,
Member of The Institution of Electrical Engineers,
Author of "Text Book on Steam and Steam Engines," &c.

Sixth Edition, Revised and Enlarged.

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PREFACE.

THE POCKET-BOOK, now submitted to the Profession, is intended to supply a want which, owing to the recent rapid extension of Electrical Engineering, is much felt. Our aim has been to make the book a practical one, without excluding those theoretical considerations on which practice is based.

The First Part deals with the fundamental principles and measurements of the science; the Second Part with their applications, including Telegraphy, Telephony, Electric-lighting, and the Transmission of Power by means of Electricity. A complete Index is appended.

We have to express our obligations to R. Tatlock, F.C.S., F.R.S.E., for his contribution on the Analysis of Materials used by electricians; to J. T. Sprague, M.S.T.E., for his treatise on Electro-metallurgy; to Thomas Fletcher, M.S.T.E., for his article on Telephonic conductors; and to H. R. Kempe, M.S.T.E., for very kindly examining the section on Testing, and permitting us to use the results of his original and valuable researches in this department.

Our best thanks are also due to the following gentlemen, who have kindly assisted us:—Sir William Thomson, F.R.S., Dr. J. Hopkinson, F.R.S., Latimer Clark, M.I.C.E., Dr. Muirhead, Conrad W. Cooke, M.S.T.E., W. F. King, F.R.S.E., J. T. Bottomley, M.A., F.R.S.E., Professor Blyth, F.R.S.E., W. Foulis, M.I.C.E., Dr. C. R. A. Wright, F.R.S., E. W. Beckinsale, A.M.I.C.E., and J. Livingston, A.S.T.E.

In a work of this kind, however great the care taken to ensure accuracy, errors will unavoidably occur, and if any should be found, we shall be glad to have our attention called to them, for the purpose of rectification. Any other suggestions or communications tending to increase the usefulness of the work will also be gratefully acknowledged.

J. MUNRO AND A. JAMIESON.

April, 1884.

PREFACE TO THE SIXTH EDITION.

THE POCKET-BOOK has been thoroughly revised and enlarged by about 120 pages and 60 new figures. We have especially to thank Professor Silvanus P. Thompson for the new chapter on Dynamos, and Mr. Gisbert Kapp for the article on Transformers. A description is given of Sir William Thomson's latest Standard Balances, Professors Ayrton and Perry's Sechommeter, as well as several other kinds of measuring apparatus and methods for calibrating them.

We are also indebted to W. H. Preece, F.R.S.; Prof. Ayrton, F.R.S.; J. T. Bottomley, F.R.S.; Captain Cardew, R.E.; Robert Tatlock, F.C.S.; the Messrs. Gray of Silvertown; Messrs. M'Whirter, Ferguson & Co.; Rankin Kennedy, M.I.E.E.; Charles Bright, A.M.Inst., C.E.; E. Payne, B.A.; James Livingston, A.I.E.E.; William Fulton, A.I.E.E.; C. H. Pownall, and others, for kind contributions and suggestions.

J. M. AND A. J.

April, 1889.

GENERAL CONTENTS.

UNITS OF MEASUREMENT, pp. 1 to 17.

Fundamental, derived, and practical, with full explanations and Tables.
Heat and Light Units.

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Areas and circumferences of circles, reciprocals.
Different Wire Gauges, with comparative Tables.

TESTING, pp. 65 to 188.

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Currents, Current and E.M.F. Galvanometers.
Electro-motive force, Resistance, Battery, Capacity tests.
Aerial lines, and their Insulators, &c.
Submarine cables during manufacture, when laying, and when submerged. Localizing faults in lines and cables.
Electric light circuits, lamps, dynamos, secondary batteries, motors.
Lightning conductors. Shunt tables for galvanometers.

CONDUCTORS, pp. 189 to 258*d*.

Copper, useful data. Conductivity and resistance tables.
German silver, iron, phosphor and silicium bronze, &c.
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Jointing and insulating leads. Conductors for aerial lines.
Specifications and tables for telephonic circuits.

DIELECTRICS, pp. 259 to 274.

Guttapercha with data, resistance and capacity tables.

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Specification, tests, electrical and mechanical data for cables made since 1872; wire-testing machine

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Diagrams of connections, with data of speaking instruments for aerial lines, telephones, and submarine cables.
Simplex and duplex translation connections.

Morse, mirror, needle and siphon-recorder alphabets.
Speed formula. Formula for stress on a cable during laying.
List of electrical and mechanical instruments and stores required on cable expeditions, Grappling, Capacity of cable tanks.

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Rules for chemical analysis of leading materials used by electrical engineers.

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Light, photometers, tests of lamps, carbons, &c., Rules and regulations regarding the same.
Cost of gas in the principal towns of Great Britain.

MISCELLANEOUS, pp. 398 to 425.

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Thermo-piles, magnetising, electro-magnets, intensity of magnetic fields.
Induction coils. Rules for erecting lightning conductors.
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Prony brake test for horse-power.
Tables of alloys used in electrical work, solders, &c.
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ELECTRICAL ENGINEERING SYMBOLS.

By Prof. Jamieson, M.Inst.C.E., &c.

Note.—In the following List of Symbols the system has been to use the *first* letter of the chief noun or most important word. Where necessary, the first letter of the adjectival substantive or qualifying words have been added as a subscript letter or letters. All specific quantities and coefficients are distinguished by small Greek letters. Further, owing to use and wont, δ, ϵ, and ω, have been retained as in the list.

Fundamental and Derived Mechanical Units.

L	for	length.
M	,,	mass.
T	,,	time.
V	,,	volume.
v	,,	velocity.
a	,,	accleration.
g	,,	,, due to gravity.
F or f	,,	force.
δ	,,	dyne; *e.g.*, 10 δ for 10 dynes.
ϵ	,,	ergs; *e.g.*, 10 ϵ for 10 ergs.
W	,,	work.
P	,,	power (general term and symbol).
w	,,	weight.
ft. lb.	,,	foot pound.
H.P. or HP	,,	horse-power.
I.H.P.	,,	indicated horse-power.
B.H.P.	,,	brake horse-power.

Symbols in General Use.

D or d	for	diameter.
r	,,	radius of anything.
τ_1 τ_2 τ_3, &c.	,,	temperatures, absolute.
t_1° t_2° t_3°, &c.	,,	,, common.
θ or d_1 d_2, &c.	,,	angle of deflection or deflections of galvanometers, &c.
n	,,	number of anything.
G	,,	galvanometer or galvanometer resistance.
s	,,	shunt or shunt resistance.
B or b	,,	battery or battery resistance.
F.P.S.	,,	foot, pound second (system).
C.G.S.	,,	centimetre, gramme, second (system).
-||-	for	battery or cells.
⊖	,,	dynamo or armature of dynamo or motor.
T +	,,	terminal positive.
T −	,,	terminal negative.
T_{aw}	,,	turns of armature wire counted all round in series.
T_{mw}	,,	total turns of magnet wire.
N_{ar}	,,	number of armature revolutions per minute.
E.M.	,,	electro-magnet.
F.M.	,,	field-magnet.
c.p.	,,	candle-power of a lamp.
A.M.	,,	amperemeter.
V.M.	,,	voltmeter.
G.P.	,,	gutta-percha.
I.R.	,,	India-rubber.
C.R.	,,	copper resistance.
S.W.G.	,,	standard wire gauge (legal).

Practical Electric Units.

R and r_1 r_2, &c.	for	res. (general for any res.)
R_I	,,	resistance insulation.
ρ	,,	resistance specific.
ω	,,	ohm; *e.g.*, 10 ω for 10 ohms.
Ω	,,	megohm; *e.g.*, 10 Ω for 10 megohms.
C and c_1 c_2, &c.	,,	current (general for any current).
A or α	,,	ampere; *e.g.*, 10 α for 10 amperes.
E and e_1 e_2, &c.	,,	electro-motive force for any E.M.F.
v	,,	volt; *e.g.*, 10 v for 10 volts.
K and k_1 k_2, &c.	,,	capacity (general for any capacity).
κ	,,	capacity specific inductive.
mfd	,,	microfarad; *e.g.*, 10 *mfd* for 10 microfarads.
Q and q_1 q_2, &c.	,,	quantity (general for coulombs).
P_W or WP	,,	power in watts, or watts.
W_J	,,	work in joules.
T_h	,,	therms or heat in gramme degrees.
J	,,	Joule's equivalent, $= 42 \times 10^6$ ergs.
z	,,	electro-chemical equivalent.
R_a R_m R_s R_e	,,	resistance of armature, main, and shunt coils, and external circuits respectively of a dynamo or motor.

C_a C_m C_s C_e	for current in armature, main, and shunt coils, and external circuits respectively of a dynamo or motor.
E_a E_b E_s E_e	,, E.M.F. or difference of potential in armature, on brushes, shunt, and external circuits respectively of a dynamo or motor.
L_s	,, coefficient of self-induction.
L_m	,, coefficient of mutual induction.

Magnetism and Magnetic Units.

Magnetic Quantities are Signified by Clarendon Block Letters in Certain Cases, to distinguish them from the Electrical and other Symbols.

N	for North pointing pole of a magnet, painted red.
S	,, South pointing pole of a magnet, painted blue.
m	,, magnet strength of pole (in C.G.S. lines).
l	,, distance between the poles of a bar magnet.
ml	,, moment of a magnet.
H or H_E	,, horizontal intensity of earth's magnetism (in C.G.S. lines).
V_E	,, vertical intensity of earth's magnetism (in C.G.S. lines).
I	,, intensity of magnetisation (in C.G.S. lines).
H	,, magnetising force or strength of field (in C.G.S. lines).
M_I or B	,, magnetic induction (in C.G.S. lines).

M_P or μ	for magnetic permeability or coefficient of magnetic induction $M_P = \frac{M_I}{H}$ or $\mu = \frac{B}{H}$.
M_S or κ	,, magnetic susceptibility or coefficient of induced magnetisation $= \frac{I}{H}$.
L_m L_{as} L_a	,, length of magnetic circuit in dynamo magnets, air space, and armature respectively.
S_m S_{as} S_a	,, section of dynamo magnets, air space, and armature respectively.
R	,, magnetic resistance of anything $= \frac{l}{M_P}$ or $\frac{l}{\mu}$.
R_m R_{as} R_a	,, magnetic resistance of *magnet* cores and yoke, *air space*, and *armature* core respectively of a dynamo or motor.
E	,, exciting magnetising force = 1·257 ampere-turns in a solenoid.
$A \times T_{mw}$	,, ampere-turns of magnet wire.
M_F	,, magnetic flux or flow or total number of lines between poles or two parts.
M_K or K_L	,, Kapp lines or unit magnetic flux or unit density for dynamo construction. One Kapp line = 6000 C.G.S. lines. One Kapp line per sq. in. = 930 C.G.S. lines per sq. centimetre.

For Formulæ in General Use.

$$C = \frac{E}{R};\ E = CR;\ R = \frac{E}{C} \text{ (ohms formula).}$$

$$E \times C = C^2 \cdot R = \frac{E^2}{R} = WP \text{ (Watts).}$$

$$E \times C \times T = C^2 \cdot R \cdot T = \frac{E^2 \cdot T}{R} = E \cdot Q = W_J$$
(work or heat in Joules).

$$\frac{E \cdot C \cdot T}{J} = \frac{C^2 \cdot R \cdot T}{J} = \frac{E^2 \cdot T}{J\,R} = \frac{E \cdot Q}{J}$$
$$= W_J \times \cdot 24 = T_h \text{ (Therms).}$$

$$C \text{ (in C.G.S. units)} = H \frac{r}{2\,\pi\,n} \cdot \tan\ \theta \text{ (tangent galvanometer).}$$

$$R = B + \frac{G \times s}{G + s} + r \text{ (for resistance of galvanometer circuit).}$$

$$K_L = \frac{E}{R_m + R_{as} + R_a} \text{ (Kapp's lines in } \mathfrak{Q} \text{ circuit).}$$

$$\text{,,} = \frac{A \times T_{mw}}{2\frac{L_m}{S_m} + 1440\frac{2\,L_{as}}{S_{as}} + 2\frac{L_a}{S_a}} \text{ (for } \mathfrak{Q} \text{ with wrought-iron cores)}$$

$$E_a = K_{L_a} \times T_{aw} \times N_{ar} \times 10^{-6} \text{ (E.M.F. in armature).}$$

See Dynamo Section for other Symbols and Formulæ.

A POCKET-BOOK

OF

ELECTRICAL RULES & TABLES.

UNITS OF MEASUREMENT.

I. Fundamental Units.—The electrical units are derived from the following mechanical units.

The *Centimetre* as a unit of *length ;*
The *Gramme* as a unit of *mass ;*
The *Second* as a unit of *time.*

The *Centimetre* is equal to 0·3937 inch in length, and nominally represents one thousand-millionth part, or $\frac{1}{1,000,000,000}$, of a quadrant of the earth.

The *Gramme* is equal to 15·432 grains, and represents the mass of a cubic centimetre of water at 4° C. *Mass* is the quantity of matter in a body.

The *Second* is the time of one swing of a pendulum making 86,164·09 swings in a sidereal day, or the 1-86,400 part of a mean solar day.

II. Derived Mechanical Units.—

Area.—The unit of area is the *square centimetre.*

Volume.—The unit of volume is the *cubic centimetre.*

Velocity is the rate of motion. It involves the idea of direction as well as that of magnitude. *Velocity* is *uniform* when the rate of motion does not change, that is, when equal spaces are traversed in equal intervals of time. The unit of velocity is the velocity of a body which moves through unit distance in unit time, or the *velocity of one centimetre per second.*

Momentum is the quantity of motion in a body, and is measured by mass × velocity.

Acceleration is the rate of change of velocity, and may be either positive or negative. The unit of acceleration is that acceleration which imparts unit change of velocity to a body in unit time, or an acceleration of one centimetre-per-second per second. The acceleration due to gravity is considerably greater than this, for the velocity imparted by gravity to falling bodies is about 981 centimetres per second (or about 32·2 feet per second). The value differs slightly in different latitudes. At Greenwich the value of the acceleration due to gravity is $g = 981{\cdot}17$; at the Equator $g = 978{\cdot}1$; at the North Pole $g = 983{\cdot}1$.

Force is that which produces motion or change of motion in a body. The unit of force is that force which, acting for one second on a mass of one gramme, gives to it a velocity of one centimetre per second. It is called the *Dyne.* The force with which the earth attracts any mass is usually called the "weight" of that mass, and its value obviously differs at different points of the earth's surface. The force with which a body gravitates, *i.e.*, its weight (in dynes), is found by multiplying its

mass (in grammes) by the value of g at the particular place where the force is exerted.

Work is the product of a force and the distance through which it acts. The unit of work is the work done in overcoming unit force through unit distance, *i.e.*, in pushing a body through a distance of one centimetre against a force of one dyne. It is called the *Erg*. Since the "weight" of one gramme is 1×981 or 981 dynes, the work of raising one gramme through the height of one centimetre against the force of gravity is 981 ergs or g ergs. One kilogramme-metre = 100,000 (g) ergs. One foot-pound = 13,825 (g) ergs, $= 1{\cdot}356 \times 10^7$ ergs.

Energy.—Kinetic energy is the work a body can do in virtue of its motion; *Potential* energy is the work a body can do in virtue of its position. The unit of energy is also the *erg*.

Power is the rate of working. The unit of power, called the *Watt*, is 10^7 ergs per second.

A Horse-power = 33,000 ft.-lbs. per minute = 550 ft.-lbs. per second; but as seen above under *Work*, 1 ft.-lb. $= 1{\cdot}356 \times 10^7$ ergs, and under *Power*, 1 *Watt* $= 10^7$ ergs per sec. ∴ a *Horse-power* $= 550 \times 1{\cdot}356 \times 10^7$ ergs = 746 Watts;

$$\text{or,} \quad \frac{EC}{746} = \frac{C^2 R}{746} = \frac{E^2}{746\,R} = \text{H.P.}$$

where E = volts, C = amperes, and R = ohms.

The French "*force de cheval*" = 75 kilogramme-metres per sec. = 736 Watts = 542·48 ft.-lbs. per sec. = ·9863 H.P.; or one H.P. = 1·01385 "*force de cheval.*"

Derived Electrical Units.—There are two systems of electrical units derived from the fundamental "C.G.S." units, one set being

based upon the force exerted between two quantities of electricity, and the other upon the force exerted between two magnetic poles. The former set are termed *electro-static* units, the latter *electro-magnetic* units.

III. Electro-static Units.—

Unit quantity of electricity is that which repels an equal and similar quantity at unit distance with unit force in air.

Unit current is that which conveys a unit quantity of electricity through a conductor in a second.

Unit electro-motive force, or *unit difference of potential*, exists between two points when the unit quantity of electricity in passing from one to the other will do the unit amount of work.

Unit resistance is that of a conductor through which unit electro-motive force between its ends can send a unit current.

Unit capacity is that of a condenser which contains unit quantity when charged to unit difference of potential.

IV. Magnetic Units.—

Unit Magnetic Pole is that which repels an equal and similar pole at unit distance with unit force.

The medium between the poles is supposed to be air.

Strength of Magnetic Field is measured by the *force* it exerts upon a unit magnetic pole: hence,

Unit Intensity of Field is that intensity of field which acts on a unit pole with unit force.

Moment of a Magnet is the strength of either pole into the distance between the poles.

Intensity of Magnetisation is the magnetic moment of a magnet divided by its volume.

Magnetic Potential.—The potential at a point due to a magnet is the work that must be done in removing a unit pole from that point to an infinite distance against the magnetic attraction, or in bringing up a unit pole from an infinite distance to that point against the magnetic repulsion.

Unit Difference of Magnetic Potential.—Unit difference of magnetic potential exists between two points when it requires the expenditure of one *erg* of work to bring a (N. or S.) unit magnetic pole from one point to the other against the magnetic forces.

V. Electro-magnetic Units.—

Unit current is one which in a wire of unit length, bent so as to form an arc of a circle of unit radius, would act upon a unit pole at the centre of the circle with unit force.

Unit quantity of electricity is the quantity which a unit current conveys in unit time.

Unit electro-motive force is that which must be maintained between the ends of a conductor, in order that unit current may do unit of work in a second.

Unit resistance is tnat of a conductor in which unit current is produced by unit electro-motive force between its ends.

Unit capacity is that of a condenser which will be at unit difference of potential when charged with unit quantity.

Dimensions of Units.—

A *line* is said to be of one dimension.

An *area* being equal to a length × a breadth,

that is, the product of two lines, is said to be of two dimensions.

A *volume* being equal to a length × a breadth × a thickness, is said to be of three dimensions.

A *velocity* being equal to a length ÷ a time $= \frac{L}{T} = L\,T^{-1}$, is said to be of one dimension in length and − 1 in time.

I. The Fundamental Units of length, mass, and time, are represented by L.M.T.

II. Derived Mechanical Units.—

Velocity, . $V = \frac{L}{T} = LT^{-1}$, . (1.)

Momentum, . $= MV = L\,M\,T^{-1}$. (1a.)

Acceleration, $A = \frac{V}{T} = VT^{-1}$

substituting for V its value from equation 1,

we have $A = L\,T^{-2}$, . . (2.)

Force, $F = \frac{M\,V}{T} = M\,V\,T^{-1} = L\,M\,T^{-2}$, . (3.)

Work, $W = F\,L =$ (equation 3) $L^2\,M\,T^{-2}$, (4.)

III. Derived Electro-Static Units.—

Quantity.—If q and q' be two quantities of positive electricity separated by a distance, L, the force of repulsion between them is, by Coulomb's law, $\frac{q\,q'}{L^2}$.

$$\therefore F = \frac{q\,q'}{L^2}.$$

$$\text{If } q = q',\ F = \frac{q^2}{L^2} = q^2 L^{-2}$$

$$\therefore q^2 = F\,L^2 = \text{(equation 3) } L^3\,M\,T^{-2}$$

$$\therefore q = L^{\frac{3}{2}}\,M^{\frac{1}{2}}\,T^{-1} \quad . \quad . \quad . \quad (5.)$$

$$\textit{Current, } c = \frac{q}{T} = qT^{-1} = \text{(equation 5) } L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-2} \quad (6.)$$

Electro-motive Force, e.—By definition unit difference of potential exists between two points, when it requires the expenditure of unit work (W, one erg) to bring a unit quantity, q, of electricity from one point to the other, against the electric force.

$$\therefore\ W = e\,q$$

$$\text{and } e = \frac{W}{q} = \frac{L^2\,M\ T^{-2}}{L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-1}} = L^{\frac{1}{2}}M^{\frac{1}{2}}\,T^{-1}, \quad (7.)$$

$$\textit{Resistance, } r = \frac{e}{c}.\ \therefore r = \frac{L^{\frac{1}{2}}\,M^{\frac{1}{2}}\,T^{-1}}{L^{\frac{3}{2}}\,M^{\frac{1}{2}}\,T^{-2}} = L^{-1}\,T, \ (8.)$$

Capacity, k.—By definition the quantity of electricity in a condenser is equal to the product of its capacity and the electro-motive force.

$$\text{or, } q = k\,e$$

$$\therefore k = \frac{q}{e} = \frac{L^{\frac{3}{2}}\,M^{\frac{1}{2}}\,T^{-1}}{L^{\frac{1}{2}}\,M^{\frac{1}{2}}\,T^{-1}} = L, \quad . \quad . \quad (9.)$$

IV.—Derived Magnetic Units.

Strength of pole or quantity of magnetism.—If m and m' be the strength of two like poles separated by a distance, L, the force of repulsion between them is $\frac{m\,m'}{L^2}$

$$\therefore\ F = \frac{m\,m'}{L^2}$$

$$\text{When } m = m',\ F = \frac{m^2}{L^2} = m^2\,L^{-2}$$

$$\therefore\ m^2 = F\,L^2 = (\text{equation 3})\ L^3\,M\,T^{-2}$$

$$\therefore\ m = L^{\frac{3}{2}}\,M^{\frac{1}{2}}\,T^{-1}, \quad . \quad . \quad (10.)$$

Moment of a magnet.—If l be the distance between the poles, and m the strength of pole,

$$\text{then } m\,l = L^{\frac{5}{2}}\,M^{\frac{1}{2}}\,T^{-1}, \quad . \quad . \quad (11.)$$

Intensity of magnetisation.—

$$\text{Intensity, } I = \frac{m\,L}{L^3} = \frac{L^{\frac{5}{2}}M^{\frac{1}{2}}T^{-1}}{L^3} = L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}, \quad (12.)$$

Magnetic Potential is the ratio of work to strength of pole.

$$= \frac{W}{m} = \frac{L^2\,M\,T^{-2}}{L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-1}} = L^{\frac{1}{2}}M^{\frac{1}{2}}\,T^{-1}, \quad . \quad (13.)$$

V.—Derived Electro-magnetic Units.

Current, C.—If a current of strength, C, flow in a wire of length, L, every part of which is at a distance, d, from a magnetic pole of strength, m, the force exerted by the current on m is $F = \frac{C L m}{d^2}$.

Substituting the L^2 for d^2 we have

$$F = \frac{C L m}{L^2} = \frac{C m}{L}.$$

$$\therefore C = \frac{F L}{m}$$

$\therefore$ by equations (4) and (10)

$$C = \frac{L^2 M T^{-2}}{L^{\frac{3}{2}} M^{\frac{1}{2}} T^{-1}} = L^{\frac{1}{2}} M^{\frac{1}{2}} T^{-1}, \quad . \quad (14.)$$

Quantity, Q. If Q be the quantity of electricity conveyed by a current, C, in time, T,

$$Q = C T$$

$$\therefore \text{(equation 14) } Q = L^{\frac{1}{2}} M^{\frac{1}{2}}, \quad . \quad (15.)$$

Electro-motive Force, E. If E be the electromotive force between the ends of a conductor, and Q the quantity sent through it, the work done

$$W = E Q$$

$$\therefore E = \frac{W}{Q}$$

∴ (equations 4 and 15)

$$E = \frac{L^2 M T^{-2}}{L^{\frac{1}{2}} M^{\frac{1}{2}}} = L^{\frac{3}{2}} M^{\frac{1}{2}} T^{-2}, \qquad (16.)$$

Resistance, R. By Ohm's law $R = \frac{E}{C}$,

∴ (equations 14 and 16)

$$R = \frac{L^{\frac{3}{2}} M^{\frac{1}{2}} T^{-2}}{L^{\frac{1}{2}} M^{\frac{1}{2}} T^{-1}} = L T^{-1} . \qquad (17.)$$

Capacity, K. By definition $K = \frac{Q}{E}$,

∴ (equations 15 and 16)

$$K = \frac{L^{\frac{1}{2}} M^{\frac{1}{2}}}{L^{\frac{3}{2}} M^{\frac{1}{2}} T^{-2}} = L^{-1} T^2 , \qquad (18.)$$

Ratio of Electro-static to Electro-magnetic Units.—From equation 17 we see that the dimensions for resistance are the same as those of a velocity—viz., $L T^{-1}$ (equation 1).

Again, if we take the two expressions for quantity by the electro-static and the electro-magnetic systems (see equations 5 and 15), and divide the one by the other, we also obtain the dimensions of a velocity, thus,

$$\frac{q}{Q} = \frac{L^{\frac{3}{2}} M^{\frac{1}{2}} T^{-1}}{L^{\frac{1}{2}} M^{\frac{1}{2}}} = L T^{-1} .$$

The latter physical quantity is usually denoted by v. Its value has been determined by experiment to be in round numbers, 3×10^{10} centimetres per second, which is the recognised velocity of light in air.

The relations between the two sets of units are as follows:—

v	electro-magnetic	unit of current	$= 1$	electro-static	units.
v	,,	,, quantity	$= 1$	,,	,,
v^2	,,	,, capacity	$= 1$	,,	,,
1	,,	units of E.M.F	$= v$	,,	unit.
1	,,	,, resistance	$= v^2$	,,	,,

Per, meaning of.—The word *per* denotes division of the quantity named before it by the quantity named after it. Thus, to compute velocity in feet per second, we must divide a number of feet by a number of seconds. (Everett on Units, p. 6.)

SYNOPSIS OF UNITS.

		Dimensions. L—M—T
I.—Fundamental.		
Length—Mass—Time,		
II.—Derived Mechanical.		
Area,	$= L \times L$,	L^2
Volume,	$= L \times L \times L$,	L^3
Velocity,	$V = L \div T$,	LT^{-1}
Momentum,	= mass × velocity,	$L\,M\,T^{-1}$
Acceleration,	A = velocity ÷ time,	LT^{-2}
Force,	F = mass × acceleration,	$L\,M\,T^{-2}$
Work,	W = force × length,	$L^2\,M\,T^{-2}$
Energy (kinetic),	= ½ mass × velocity²,	$L^2\,M\,T^{-2} \div 2$
III.—Derived Electro-Static.		
Quantity,	$q = vQ = \sqrt{\text{force} \times \text{distance}^2}$,	$L^{\frac{3}{2}}\,M^{\frac{1}{2}}\,T^{-1}$
Current,	$c = vC$ = quantity ÷ time,	$L^{\frac{3}{2}}\,M^{\frac{1}{2}}\,T^{-2}$
Electro-motive Force, Difference of Potential,	$e = \frac{E}{v}$ = work ÷ quantity,	$L^{\frac{1}{2}}\,M^{\frac{1}{2}}\,T^{-1}$
Resistance,	$r = \frac{R}{v^2}$ = electro-motive force ÷ current,	$L^{-1}\,T$
Capacity,	$k = v^2K$ = quantity ÷ electro-motive force,	L
Sp. Ind. Capacity,	= quantity ÷ another quantity,	a numeral.

SYNOPSIS OF UNITS.

IV.—Derived Magnetic.		Dimensions.
Strength of Pole, . . . Quantity of Magnetism,	$m = \sqrt{\text{force} \times \text{distance}^2}$, ...	$L^{\frac{3}{2}} M^{\frac{1}{2}} T^{-1}$
Moment of a Magnet, .	ml = strength of pole × length between poles, .	$L^{\frac{5}{2}} M^{\frac{1}{2}} T^{-1}$
Intensity of Magnetisation,	I = moment of magnet ÷ volume, . . .	$L^{-\frac{1}{2}} M^{\frac{1}{2}} T^{-1}$
Magnetic Potential, ...	= work ÷ strength of pole, ...	$L^{\frac{1}{2}} M^{\frac{1}{2}} T^{-1}$
V.—Derived Electro-Magnetic.		
Current, ...	$C = \frac{c}{v}$ = intensity of field × length, . . .	$L^{\frac{1}{2}} M^{\frac{1}{2}} T^{-1}$
Quantity, ...	$Q = \frac{q}{v}$ = current × time = C T, ...	$L^{\frac{1}{2}} M^{\frac{1}{2}}$
Electro-motive Force, Difference of Potential,	$E = ev$ = work ÷ quantity, ...	$L^{\frac{3}{2}} M^{\frac{1}{2}} T^{-2}$
Resistance, ...	$R = rv^2$ = electro-motive force ÷ current, . .	$L T^{-1}$
Capacity, ...	$K = \frac{k}{v^2}$ = quantity ÷ electro-motive force, .	$L^{-1} T^{2}$
Ratio of electro-magnetic to electro-static unit of quantity, $v = 3 \times 10^{10}$ centimetres per second approximately, ...		$L T^{-1}$

SYNOPSIS OF PRACTICAL UNITS.

Unit.	Symbol.	Name.	Derivation.	Value.	
				C.G.S.	Equivalent.
E. M. F., .	E	Volt.	Ampere × ohm.	10^{8}	·926 standard Daniell cell.
Resistance,	R	Ohm.	Absolute, see p. 14,	10^{9}	106 cm. mercury, 1 sq. mm. section at 0° Cent.
Current, .	C	Ampere.	Absolute, see p. 14.	10^{-1}	
Quantity, .	Q	Coulomb.	Ampere × second.	10^{-1}	1·118 milligrammes of silver deposited per second.
Capacity, .	K	Farad.	Coulomb ÷ volt.	10^{-9}	
,, .	,,	Microfarad.	1 millionth farad.	10^{-15}	2·5 knots of D. U. S. cable.
Power, . .	Pw	Watt.	Volt × ampere	10^{7}	·0013405 or $\frac{1}{746}$ horse-power.
Work, . .	WJ	Joule.	Volt × coulomb.	,,	·7373 ft.-lbs. in a second.
Heat, . .			Amp.^{2} × sec. × ohm.	,,	·238 calorie or Therm.
Self Induction, . .	L_s	Secohm.	Second × ohm.	10^{9}	Apparent increased res.

PRACTICAL ELECTRIC UNITS.

For electrical measurements the fundamental units, the centimetre (for length), the gramme (for mass), and the second (for time), forming the C.G.S. system, are adopted.

Resistance, R.—The **Ohm** is equal to 10^9 C.G.S.* units of resistance. The **Legal Ohm** (Paris Congress, April, 1884) is the resistance of a column of pure mercury, 1 square millimetre in section, and 106 centimetres long at the temperature of melting ice.

Since the *true ohm* is estimated as the resistance of 106·2 cms. of mercury 1 sq. mm. section at 0° C.; the *legal ohm* = (106 ÷ 106·2) or ·998 true ohm = 1·0112 B.A. units; while the B.A. unit contains ·9889 legal ohm.

Measurements made with resistance coils, adjusted to old ohms or B. A. units, have to be divided by 1·0112, or multiplied by ·9889 (*i.e.*, deduct 1·12°/₀) to give legal ohms. German silver coils having a coef. for temp. equal to ·044°/₀ per degree cent., adjusted at 0°C., become legal ohms at 25°·5C., or 78°F. Platinum silver coils having a coef. for temp. equal to ·031°/₀ per degree cent., adjusted at 0°C., become legal ohms at 36°·1C., or 97°F. (See p. 196.)

The **Megohm** = one million ohms. The **Microhm** = one millionth ohm. The **Siemens Mercury Unit** (length 1 metre, section 1 sq. mm. at 0°C.) = ·9540 B. A. unit = ·9434 legal ohm.

Current, C.—The **Legal Ampere** (Paris Congress, April, 1884) is the current, of which the absolute measurement is 10^{-1} C.G.S.* units.

One ampere decomposes ·00009324 gramme of water (H_2O) per second, or deposits 1·118 milligrms. of silver per sec. = 4·025 grms. per hour.

The **Milliampere** = $\frac{1}{1000}$ of an ampere.

Electro-motive Force, E.—The **Volt** is equal to 10^8 C.G.S.* units of electro-motive force, or about 7 per cent. less than the E.M.F. of a standard Daniell's cell. Electro-motive force is equivalent to the difference of potential between two points. The **Legal Volt** (Paris Congress,

* Electro-magnetic system.

April, 1884) is the electro-motive force which maintains a current of 1 ampere in a conductor whose resistance is the legal ohm.

Quantity, Q.—The **Coulomb** is equal to 10^{-1} C.G.S.* units of quantity. It is the quantity of electricity given by an ampere in a second.

Capacity, K.—The **Farad** is equal to 10^{-9} C.G.S.* units of capacity. It is the capacity defined by the condition that a coulomb charges it to the potential of a volt.

The **Microfarad,** *mfd.* = 10^{-15} C.G.S.* units of capacity, or one-millionth of a Farad.

Self-Induction, L_s.—The **Secohm** is equal to 10^9 centimetres or earth's quadrant.

The **Legal Secohm** will thus be $\cdot 998 \times 10^9$ cms., due to difference between the true and the legal ohm. Standard coils of self-induction have not been made yet. See Vol. xvi., No. 67, *Journal Soc. Tel. Engs. and Elects*

Power, P_W.—The **Watt** is equal to 10^7 C.G.S.* units of power. It is the power conveyed by a current of an ampere through a conductor whose ends differ in potential by a volt; or, in other words, the rate of doing work when an ampere passes through an ohm, and it is equal to 10^7 ergs per second, or a Joule per second ($\frac{1}{746}$ of a H.P.)

$$\therefore\ E \times C = C^2 \times R = E^2 \div R = \text{Watts},$$

$$\text{and } \frac{E \times C}{746} = \frac{C^2 \times R}{746} = \frac{E^2}{746\ R} = \text{Horse-power.}$$

The *Board of Trade Commercial Unit* is 1000 volt-ampere-hours or 1000 Watt-hours; 10 amperes at 100 volts an hour = one B.T. unit, or equal to 1·34 H.P. working for one hour.

Heat or Work, W_J—The **Joule** is equal to 10^7 C.G.S.* units of work or ergs. It is the work done, or heat generated by a Watt in a second—*i.e.*, the work done, or heat generated in a second by an ampere flowing through the resistance of an ohm, or the heat generated by a Coulomb running down through a

* Electro-magnetic system.

difference of potential of 1 volt. It is therefore the amount of heat equivalent to 10^7 ergs. Assuming Joule's equivalent = 42,000,000, it is the heat necessary to raise ·238 gramme of water 1°C.

$$\therefore E C T = C^2 R T = E^2 T \div R = E Q = \text{Joules.}$$

And since 1 horse-power = 550 foot-pounds of work per second,

$$W_J = \frac{550}{746} E Q = \cdot 7373 \, E Q \text{ ft.-lb.}$$

HEAT UNITS.

Heat Units, Th. — The **Therm** or French **calorie** is the amount of heat required to raise 1 gramme mass of water, from 4° (temperature of maximum density) to 5° Cent. = 1 gramme degree Cent.

The **English Unit** is the amount of heat required to raise 1 pound of water, from 60° Fah. to 61° = 1 pound degree Fah.

Joule's Equivalent, J, is the amount of energy equivalent to a unit of heat.

For 1 gramme-degree Cent. $J = 4 \cdot 2 \times 10^7$ ergs
= 42 million ergs.
" 1 pound-degree " $J = 1 \cdot 91 \times 10^{10}$ ergs.
" 1 " " Fah. $J = 1 \cdot 06 \times 10^{10}$ ergs
= 772 ·55 foot pounds.

The Heat generated in time, T, (seconds) by a current, C, through a wire of resistance, R, is $\frac{C^2 R T}{J} = \frac{E C T}{J}$ (therms), where $J = 4 \cdot 2 \times 10^7$, and C, R, and E are expressed either in absolute electro-magnetic or electro-static units.

For practical use when C is amperes, R ohms, E volts, and T seconds, the heat generated in time, T, $= C^2 R T \times 0 \cdot 24$, or $E C T \times 0 \cdot 24$ therms.

LIGHT UNITS.

The British Unit is the light of a spermaceti candle $\frac{7}{8}$ inch in diameter, burning 120 grains per hour; (six candles weigh 1 pound). They sometimes vary 10 per cent. from the standard.

Mr. Vernon Harcourt's standard flame equals the average of one English standard candle. It consists of an air-gas flame, $2\frac{1}{2}$ inches in height, rising from an opening $\frac{1}{4}$ inch diameter.

Mixture of air and pentane: 576 volumes of air to one of liquid pentane at 60° Fah., or if both are in form of gas 20 of air to 7 of pentane.

The French Unit of Light or Bec-Carcel is the light of a Carcel lamp, burning 42 grammes of pure Colza oil per hour with a flame 40 mm. high, under conditions fixed by J. B. Dumas, and Regnault. It is taken = 9·5 British standard candles.

The German Unit is the light of a paraffin candle 20 millimetres in diameter, burning with a flame 5 centimetres high.

The Bec-Carcel is taken = 7·6 German candles.

The Legal Standard of Light (Paris Congress, April, 1884).—The unit of each simple light, is the quantity of light of the same kind emitted in the normal direction by a square centimetre of surface of molten platinum at the temperature of solidification. The practical unit of white light, is the quantity of light emitted normally by the same source.

A sq. ft. of surface is equally illuminated by a standard candle, at a distance of 12·7 inches, and by a Bec-Carcel at a distance of 1 metre. A 16 c.p. lamp, at 4 ft. 2 ins., gives the same illumination. (See p. 386.)

WEIGHTS AND MEASURES.

Avoirdupois Weight.

drachms.	oz.	lbs.	qrs.	cwts.	ton.	French grammes.
1=	·0625=	·0039=	·000139=	·000035=	·00000174=	1·771846
16=	1=	·0625=	·00223 =	·000558=	·000028	=28·34954
256=	16=	1 =	·0357	= ·00893	= ·000447	=453·59
7168=	448=	28 =	1	= ·25	= ·0125	=12,700
28672=	1792=	112 =	4	=1	= ·05	=50,802
573440=	35840=	2240 =	80	=20	=1	=1,016,048

Troy Weight.

grains.	dwts.	oz.	lb.	French grammes.
1=	·04167=	·00208=	·0001736=	·0648
24=	1 =	·05 =	·004167 =	1·555
480=	20 =	1 =	·0833 =	31·1035
5760=	240 =	12 =	1 =	373·242

7000 grains troy = 1 lb. avoirdupois.
175 lbs. troy = 144 lbs. avoirdupois.
lbs. avoirdupois × 1·2153 = lbs. troy.
lbs. troy .. × ·82286 = lbs. avoirdupois.

Long Measure.

ins.	feet.	yards.	fath.	poles.	furl.	mile.	French mètres.
1=	·083 =	·02778=	·0139=	·005 =	·000126=	·0000158=	·0254
12=	1 =	·333 =	·1667=	·0606=	·00151 =	·0001894=	·3048
36=	3 =	1 =	·5 =	·182 =	·00454 =	·000568 =	·9144
72=	6 =	2 =	1 =	·364 =	·0091 =	·001136 =	1·8287
198=	16½=	5½=	2¾=	1 =	·025 =	·003125 =	5·0293
7920=	660 =	220 =	110 =	40 =	1 =	·125 =	201·16
63360=	5280 =	1760 =	880 =	320 =	8 =	1 =	1609·315

Measure of Capacity.

pints.	gall.	peck.	bushel.	quarter.	wey.	last.	cub. ft.	litres.
1=	·125=	·0625=	·01562=	·00195=	·00039=	·000195=	·02 =	·5676
8=	1=	·5 =	·125 =	·0156 =	·00312=	·00156 =	·1604=	4·543
16=	2=	1 =	·25 =	·03125=	·00625=	·00312 =	·3208=	9·082
64=	8=	4 =	1 =	·125 =	·025 =	·0125 =	1·283 =	36·32816
512=	64=	32 =	8 =	1 =	·2 =	·1 =	10·264=	290·625
2560=	320=	160 =	40 =	5 =	1 =	·5 =	51·319=	1453·126
5120=	640=	320 =	80 =	10 =	2 =	1 =	102·64=	2906·25

1 gallon in wine, ale, or dry measure
= 277¼ cubic inches = ·16 cubic foot
= 10 lbs. of distilled water =
Cube feet × 6·2355 = gallons.
Cube ins. × ·003607 = gallons.
1 bushel = 2218·19 cube inches = 1·28 cube foot.
Cube feet = ·78 = bushels.
Cube ins. × ·00045 = bushels.

Approximate Values of English and French Measures.

One metre = 3·28 feet = 3 feet 3 inches and $\frac{3}{8}$ths (all but $\frac{1}{512}$ inch) = 40 inches nearly ($\frac{1}{64}$ or 1·6 per cent. less).

One decimetre (·100 metre) = 4 inches nearly (exactly $3\frac{15}{16}$ inches).

One centimetre (·010 metre) = ·4 inches, or $\frac{4}{10}$ inch nearly.

One millimetre (·001 metre) = ·04 inches, or

$\frac{4}{100}$ inch, or two-thirds of $\frac{1}{16}$ inch, or $\frac{1}{25}$ inch nearly.

One inch is about $2\frac{1}{2}$ centimetres (exactly 2·54).

One inch is about 25 millimetres (exactly 25·4).

One yard is $\frac{11}{12}$ of a metre. Thus 11 metres are equal to 12 yards.

To convert metres or parts of metres into yards, add $\frac{1}{11}$.

To convert metres into inches, multiply by 40.

To convert inches into metres, divide by 40.

One kilometre (1,000 metres) is about $\frac{5}{8}$ mile (it is 0·6 per cent. less).

One mile is about $1\frac{5}{8}$ kilometres (it is 1 per cent. less).

One square centimetre is about $\frac{1}{6 \cdot 5}$ part of a square inch.

One square inch is 6·5 square centimetres.

One square metre contains nearly 11 square feet, or nearly $1\frac{1}{5}$ square yards.

One square yard is nearly $\frac{6}{7}$ of a square metre.

One acre is over 4,000 square metres (it is about 1·2 per cent. more).

One square mile is nearly 260 hectares or metrical acres (10,000 square metres). It is about 0·4 per cent. less.

One cubic yard is about $\frac{3}{4}$ cubic metre (it is 2 per cent. more).

One cubic metre is nearly $1\frac{1}{3}$ cubic yards (it is $1\frac{2}{3}$ per cent. less).

One cubic metre is nearly $35\frac{1}{3}$ cubic feet (it is ·05 per cent. less).

One litre is over $1\frac{3}{4}$ pints (it is 0·57 per cent. more).

One gallon contains above $4\frac{1}{2}$ litres (it holds about 1 per cent. more).

One kilolitre (a cubic metre) holds nearly 1 ton of water at 62° Fah. ($1\frac{3}{4}$ per cent. less).

One cubic foot contains 28·3 litres.

One gramme is nearly $15\frac{1}{2}$ grains (about $\frac{1}{2}$ per cent. less).

One kilogramme is about $2\frac{1}{5}$ lbs. (about $\frac{1}{4}$ per cent. more).

One thousand kilogrammes, or a metric ton, is nearly one English ton (about $1\frac{1}{2}$ per cent. less).

One hundred-weight is nearly 51 kilogrammes ($\frac{2}{5}$ per cent. less).

One kilogrammetre is = 7·233 ft. lbs.

One foot pound = ·138 kilogrammetres.

The CHAIN, in LAND MEASURE, is subdivided into 4 *poles* or *perches* (each of $5\frac{1}{2}$ yards) and 100 *links* (each of 7·92 inches).

	Inches.	Feet.	Yards.	Statute Miles.	Metres.
Chain,	792	66	22	$\frac{1}{80}$	20·11662

A FATHOM is two yards.

The GEOGRAPHICAL, NAUTICAL, or SEA MILE, or KNOT, depends on the dimensions of the earth, which are known approximately only. The following are estimates of its value :—

	Feet nearly.	Statute Mile nearly	Metres nearly.
Mean length of one minute of longitude at the equator; being the nautical mile by Admiralty Regulation, . .	6,086	1·1527	1,855
Mean length of one minute of latitude, ...	6,076	1·1508	1,852
* One telegraph knot = 2,029 yds.	6,087	1·1528	1,855·3

A LEAGUE is three nautical miles.

The nautical mile is sometimes subdivided into 10 *cables* and 1,000 *fathoms;* the fathom thus obtained being about $\frac{1}{80}$ part longer than the common fathom.

The French *nœud* = British nautical mile.

* See Tables, pages 26 and 27.

Decimal Equivalents of Inches, Feet, and Yards.

Fractions of an Inch.	Decims. of an Inch.	Decims. of a Foot.
	·0625	= ·00521
$\frac{1}{8}$	·125	= ·01041
	·1875	= ·01562
$\frac{1}{4}$	·25	= ·02083
	·3125	= ·02604
$\frac{3}{8}$	·375	= ·03125
	·4375	= ·03646
$\frac{1}{2}$	·5	= ·04166
	·5625	= ·04687
$\frac{5}{8}$	·625	= ·05208
	·6875	= ·05729
$\frac{3}{4}$	·75	= ·06250
	·8125	= ·06771
$\frac{7}{8}$	·875	= ·07292
	·9375	= ·07812
1 inch	1·00	= ·08333

Inches.	Feet.	Yards.
1 =	·0833	= ·0278
2 =	·1666	= ·0556
3 =	·25	= ·0833
4 =	·3333	= ·1111
5 =	·4166	= ·1389
6 =	·5	= ·1667
7 =	·5833	= ·1944
8 =	·6666	= ·2222
9 =	·75	= ·25
10 =	·8333	= ·2778
11 =	·9166	= ·3056
12 =	1·000	= ·3333

Measures in which the Length of Over-head Lines are Expressed in Various Countries.

		Length in English Yards.			English Miles.		English Miles.		Miles, &c., of different Countries.
Arabia,	Mile,	2148	100	=	122·04	and	100	=	81·93
Austria,	Mile,	10126	do.		575·34	„	do.		17·38
Bohemia,	Mile,	10137	do.		575·96	„	do.		17·36
Brabant,	League,	6076	do.		345·22	„	do.		28·96
Burgundy,	League,	6183	do.		351·66	„	do.		28·46
China,	Li,	632	do.		35·91	„	do.		278·48
Denmark,	Mile,	8244	do.		468·41	„	do.		21·35
England,	Mile,	1760	do.		100·	„	do.		100·
Flanders,	League,	6864	do.		390·	„	do.		25·64
France,	Kilomètre,	1093	do.		62·10	„	do.		161·02
Hamburg,	Mile,	8244	do.		468·41	„	do.		21·35
Hanover,	Mile,	11559	do.		656·76	„	do.		15·22
Hesse,	Mile,	10547	do.		599·26	„	do.		16·68
Holland,	Mile,	8101	do.		460·28	„	do.		21·72
Hungary,	Mile,	9113	do.		517·78	„	do.		19·31
Italy,	Mile,	2025	do.		115·05	„	do.		86·91

Measures in which the Length of Over-head Lines are Expressed in Various Countries—*Continued.*

		Length in English Yards.			English Miles.			English Miles.		Miles, &c., of different Countries.
Lithuania,	Mile,	9781	100	=	555·73	and	100	=	18·00
Norway,	Mile,	12352	do.		701·83	„	do.		14·25
Oldenburg,	Mile,	10820	do.		614·77	„	do.		16·26
Poland,	Long Mile,	8101	do.		460·28	„	do.		21·72
„	Short Mile,	6075	do.		345·17	„	do.		28·97
Portugal,	League,	6760	do.		384·09	„	do.		26·03
Prussia,	Mile,	8237	do.		480·68	„	do.		21·37
Rome,	Mile,	1628	do.		92·50	„	do.		108·11
Russia,	Verst,	1167	do.		66·30	„	do.		150·81
Saxony,	Mile,	9905	do.		562·78	„	do.		17·76
Silesia,	Mile,	7083	do.		402·44	„	do.		24·84
Spain,	Common Legua of 8000 Varas,	7416	do.		421·36	„	do.		23·73
„	Legal Legua of 5000 Varas,	4635	do.		275·34	„	do.		37·97
Swabia,	Mile,	10126	do.		563·35	„	do.		17·38
Sweden,	Mile,	11700	do.		664·77	„	do.		15·04
Switzerland,	Mile,	9153	do.		520·05	„	do.		19·23
Turkey,	Berri,	1826	do.		103·75	„	do.		96·38
Tuscany,	Mile,	1808	do.		102·72	„	do.		97·34
Westphalia,	Mile,	12151	do.		690·39	„	do.		14·48

Telegraph Knots into Miles.

Table for the Conversion of Knots of 2029 Yards into Statute Miles of 1760 Yards.

Knots.	0	1	2	3	4	5	6	7	8	9
0	...	1·1528	2·3057	3·4585	4·6114	5·7642	6·9170	8·0699	9·2127	10·3756
10	11·5284	12·6812	13·8341	14·9869	16·1398	17·2926	18·4454	19·5983	20·7511	21·9040
20	23·0568	24·2096	25·3625	26·5153	27·6682	28·8210	29·9738	31·1267	32·2795	33·4324
30	34·5852	35·7380	36·8909	38·0437	39·1966	40·3494	41·5022	42·6551	43·8079	44·9608
40	46·1136	47·2664	48·4193	49·5721	50·7250	51·8778	53·0306	54·1835	55·3363	56·4892
50	57·6420	58·7948	59·9477	61·1005	62·2534	63·4062	64·5590	65·7119	66·8647	68·0176
60	69·1704	70·3232	71·4761	72·6289	73·7818	74·9346	76·0874	77·2403	78·3931	79·5460
70	80·6988	81·8516	83·0045	84·1573	85·3102	86·4630	87·6158	88·7687	89·9215	91·0744
80	92·2272	93·3800	94·5329	95·6857	96·8386	97·9914	99·1442	100·2971	101·4499	102·6028
90	103·7556	104·9084	106·0613	107·2141	108·3670	109·5198	110·6726	111·8255	112·9783	114·1312

Miles into Telegraph Knots.

Table for the Conversion of Statute Miles of 1760 Yards into Knots of 2029 Yards.

Statute Miles.	0	1	2	3	4	5	6	7	8	9
...	...	0·8674	1·7348	2·6023	3·4697	4·3371	5·2045	6·0719	6·9394	7·8068
10	8·6742	9·5416	10·4091	11·2765	12·1439	13·0113	13·8787	14·7462	15·6136	16·4810
20	17·3484	18·2158	19·0833	19·9507	20·8181	21·6856	22·5530	23·4204	24·2878	25·1552
30	26·0227	26·8901	27·7575	28·6249	29·4924	30·3598	31·2272	32·0946	32·9620	33·8295
40	34·6969	35·5643	36·4318	37·2992	38·1666	39·0340	39·9014	40·7689	41·6363	42·5037
50	43·3711	44·2386	45·1060	45·9734	46·8408	47·7082	48·5757	49·4431	50·3105	51·1779
60	52·0453	52·9128	53·7802	54·6476	55·5150	56·3825	57·2499	58·1173	58·9847	59·8521
70	60·7196	61·5870	62·4544	63·3218	64·1892	65·0567	65·9241	66·7915	67·6590	68·5264
80	69·3938	70·2612	71·1286	71·9960	72·8635	73·7309	74·5983	75·4657	76·3332	77·2006
90	78·0680	78·9354	79·8028	80·6703	81·5377	82·4051	83·2725	84·1400	85·0074	85·8748

Multipliers for Converting British Measures.

	Links into Feet.	Feet into Links.	Square Links into Square Feet.	Square Feet into Square Links.	
1	0·66	1·51515	0·4356	2·2957	1
2	1·32	3·03030	0·8712	4·5914	2
3	1·98	4·54545	1·3068	6·8871	3
4	2·64	6·06061	1·7424	9·1827	4
5	3·30	7·57576	2·1780	11·4784	5
6	3·96	9·09091	2·6136	13·7741	6
7	4·62	10·60606	3·0492	16·0698	7
8	5·28	12·12121	3·4848	18·3655	8
9	5·94	13·63636	3·9204	20·6612	9
10	6·60	15·15152	4·3560	22·9568	10

	Mean Geographical Miles into Statute Miles.	Statute Miles into Mean Geographical Miles.	Tons into Lbs.	Lbs. into Tons.	
1	1·151	0·869	2,240	·0004464	1
2	2·302	1·738	4,480	·0008929	2
3	3·452	2·607	6,720	·0013393	3
4	4·603	3·476	8,960	·0017857	4
5	5·754	4·345	11,200	·0022321	5
6	6·905	5·214	13,440	·0026786	6
7	8·056	6·083	15,680	·0031250	7
8	9·207	6·952	17,920	·0035714	8
9	10·357	7·821	20,160	·0040179	9
10	11·508	8·690	22,400	·0044643	10

	Tons Displacement into Cubic Feet.	Cubic Feet into Tons Displacement.	Lbs. on the Square Inch into Lbs. on the Square Foot.	Lbs. on the Square Foot into Lbs. on the Square Inch.	
1	35	·02857	144	·00694	1
2	70	·05714	288	·01389	2
3	105	·08571	432	·02083	3
4	140	·11429	576	·02778	4
5	175	·14286	720	·03472	5
6	210	·17143	864	·04167	6
7	245	·20000	1,008	·04861	7
8	280	·22857	1,152	·05556	8
9	315	·25714	1,296	·06250	9
10	350	·28571	1,440	·06944	10

	Lbs. Avoir. into Grains.	Grains into Lbs. Avoir.	Cubic Feet into Gallons.	Gallons into Cubic Feet.	
1	7,000	0·000142857	6·2355	0·16037	1
2	14,000	0·000285714	12·4710	0·32074	2
3	21,000	0·000428571	18·7065	0·48112	3
4	28,000	0·000571429	24·9420	0·64149	4
5	35,000	0·000714286	31·1775	0·80186	5
6	42,000	0·000857143	37·4130	0·96223	6
7	49.000	0·001000000	43·6485	1·12260	7
8	56,000	0·001142857	49·8840	1·28298	8
9	63.000	0·001285714	46·1195	1·44335	9
10	70,000	0·001428571	62·3550	1·60372	10

Values of Decimal Fractions of a Pound Sterling in Shillings and Pence.

£		s.	d.	£		s.	d.	£		s.	d.
·001	=	0	0·24	·01	=	0	2·4	·1	=	2	0
·002	=	0	0·48	·02	=	0	4·8	·2	=	4	0
·003	=	0	0·72	·03	=	0	7·2	·3	=	6	0
·004	=	0	0·96	·04	=	0	9·6	·4	=	8	0
·005	=	0	1·20	·05	=	1	0·0	·5	=	10	0
·006	=	0	1·44	·06	=	1	2·4	·6	=	12	0
·007	=	0	1·68	·07	=	1	4·8	·7	=	14	0
·008	=	0	1·92	·08	=	1	7·2	·8	=	16	0
·009	=	0	2·16	·09	=	1	9·6	·9	=	18	0

Values of Farthings, Pence, and Shillings in Decimal Fractions of a Pound.

Farthings.	£
1	·0010417
2	·0020833
3	·0031250
Pence	
1	·004167
1½	·006250
2	·008333
3	·012500
4	·016667
4½	·018750
5	·020833
6	·025000
7	·029167
7½	·031250
8	·033333
9	·037500
10	·041667
10½	·043750
11	·045833

Shillings.	£
1	·05
2	·10
3	·15
4	·20
5	·25
6	·30
7	·35
8	·40
9	·45
10	·50
11	·55
12	·60
13	·65
14	·70
15	·75
16	·80
17	·85
18	·90
19	·95

MULTIPLIERS.

	Metres into Feet.	Feet into Metres.	Millimetres into Inches.	Inches into Millimetres.	
1	3·2809	0.3048	·03937	25·400	1
2	6·5617	0·6096	·07874	50·800	2
3	9·8426	0·9144	·11811	76·199	3
4	13·1235	1·2192	·15748	101·599	4
5	16·4043	1·5240	·19685	126·999	5
6	19·6852	1·8288	·23622	152·399	6
7	22·9661	2·1336	·27559	177·798	7
8	26·2470	2·4384	·31496	203·198	8
9	29·5278	2·7432	·35433	228·598	9
10	32·8087	3·0480	·39370	253·998	10

	Square Metres into Square Feet.	Square Feet into Square Metres.	Square Millimetres into Square Inches.	Square Inches into Square Millimetres.	
1	10·764	·0929	·0015500	645·15	1
2	21·528	·1858	·0031001	1290·30	2
3	32·292	·2787	·0046501	1935·44	3
4	43·056	·3716	·0062001	2580·59	4
5	53·821	·4645	·0077501	3225·74	5
6	64·585	·5574	·0093002	3870·89	6
7	75·349	·6503	·0108502	4516·04	7
8	86·113	·7432	·0124002	5161·18	8
9	96·877	·8361	·0139503	5806·33	9
10	107·641	·9290	·0155003	6451·48	10

	Cubic Metres into Cubic Feet.	Cubic Feet into Cubic Metres.	Cubic Millimetres into Cubic Inches.	Cubic Inches into Cubic Millimetres.	
1	35·316	·028316	·00006103	16387	1
2	70·631	·056632	·00012205	32773	2
3	105·947	·084948	·00018308	49160	3
4	141·262	·113264	·00024410	65546	4
5	176·578	·141581	·00030513	81933	5
6	211·894	·169897	·00036615	98320	6
7	247·209	·198213	·00042718	114706	7
8	282·525	·226529	·00048820	131093	8
9	317·840	·254845	·00054923	147480	9
10	353·156	·283161	·00061025	163866	10

	Grammes into Grains.	Grains into Grammes.	Kilogrammes into Lbs.	Lbs. into Kilogrammes.	
1	15·4323	·06480	2·2046	0·4536	1
2	30 8647	·12960	4·4092	0·9072	2
3	46·2970	·19440	6·6139	1·3608	3
4	61·7294	·25920	8·8185	1·8144	4
5	77·1617	·32399	11·0231	2·2680	5
6	92·5941	·38879	13·2277	2·7216	6
7	108·0264	·45359	15·4323	3·1751	7
8	123 4588	·51839	17·6370	3·6287	8
9	138 8911	·58319	19·8416	4·0823	9
10	154·3235	·64799	22·0462	4·5359	10

	Tonneaux into Tons.	Tons into Tonneaux.	Litres into Gallons.	Gallons into Litres.	
1	0·9842	1·0160	0·2202	4·541	1
2	1·9684	2·0321	0·4404	9·082	2
3	2·9526	3·0481	0·6606	13·623	3
4	3·9368	4·0642	0 8809	18·164	4
5	4·9210	5·0802	1·1011	22·705	5
6	5·9052	6·0963	1·3213	27·246	6
7	6·8894	7·1123	1·5415	31·787	7
8	7·8736	8·1284	1·7617	36·328	8
9	8·8579	9·1444	1·9819	40·869	9
10	9·8421	10·1605	2·2021½	45·410	10

	Kilogrammetres into Foot-Lbs.	Foot-Lbs. into Kilogrammetres.	Kilogrammes on the Square Millimetre into Lbs. on the Square Inch.	Lbs. on the Sq. Inch into Kilogrammes on the Square Millimetre.	
1	7·233	0·13825	1422	·000703	1
2	14·466	0·27651	2845	·001406	2
3	21·699	0·41476	4267	·002109	3
4	28·932	0·55302	5689	·002812	4
5	36·165	0·69127	7111	·003515	5
6	43·398	0·82952	8534	·004219	6
7	50·632	0·96778	9956	·004922	7
8	57·865	1·10603	11378	·005625	8
9	65·098	1·24429	12801	·006328	9
10	72·331	1·38254	14223	·007031	10

	Kilometres into Miles.	Miles into Kilometres.	Hectares into Acres.	Acres into Hectares.	
1	0·6214	1·6093	2·471	0·4047	1
2	1·2428	3·2186	4·942	0·8094	2
3	1·8641	4·8280	7·413	1·2140	3
4	2·4855	6·4373	9·884	1·6187	4
5	3·1069	8·0467	12·356	2·0234	5
6	3·7283	9·6560	14·827	2·4281	6
7	4·3496	11·2653	17·298	2·8328	7
8	4·9710	12·8747	19·769	3·2375	8
9	5·5924	14·4840	22·240	3·6421	9
10	6·2138	16·0933	24·711	4·0468	10

	Francs into £.	£ into Francs.	Francs into Pence.	Pence into Francs.	
1	·03965	25·22	9·516	0·10508	1
2	·07930	50·44	19·033	0·21017	2
3	·11895	75·66	28·549	0·31525	3
4	·15860	100·88	38·065	0·42033	4
5	·19826	126·10	47·581	0·52542	5
6	·23791	151·32	57·098	0·63050	6
7	·27756	176·54	66·614	0·73558	7
8	·31721	201·76	76·130	0·84067	8
9	·35686	226·98	85·646	0·94575	9
10	·39651	252·20	95·163	1·05083	10

VELOCITIES.

	Miles per Hour into Feet per Second.	Feet per Second into Miles per Hour.	Knots per Hour into Feet per Second.	Feet per Second into Knots per Hour.	
1	1·467	0·682	1·688	0·592	1
2	2·933	1·364	3·376	1·185	2
3	4·400	2·045	5·064	1·777	3
4	5·867	2·727	6·752	2·370	4
5	7·333	3·409	8·439	2·962	5
6	8·800	4·091	10·127	3·555	6
7	10·267	4·773	11·815	4·147	7
8	11·733	5·455	13·503	4·740	8
9	13·200	6·136	15·191	5·332	9
10	14·667	6·818	16·879	5·925	10

Velocities.

	Knots per Hour into Metres per Second.	Metres per Second into Knots per Hour.	Angular Velocity. Turns per Second into Circular Measure.	Angular Velocity. Circular Measure into Turns per Second.	
1	0·5144	1·944	6·28	0·159	1
2	1·0288	3·888	12·57	0·318	2
3	1·5432	5·832	18·85	0·477	3
4	2·0576	7·776	25·13	0·637	4
5	2·5720	9·720	31·42	0·796	5
6	3·0864	11·664	37·70	0·955	6
7	3·6008	13·608	43·98	1·114	7
8	4·1152	15·552	50·27	1·273	8
9	4·6296	17·496	56·55	1·432	9
10	5·1440	19·440	62·83	1·592	10

Pressures in Atmospheres.

Atmospheres.	Lbs. on the Square Inch.	Lbs. on the Square Foot.	Kilogrammes on the Square Metre.	Millimetres of Mercury.	Inches of Mercury.	Feet of Water.
1	14·7	[illegible]6	10333	760	29·922	33·9
2	29·4	4233	20666	1520	59·844	67·8
3	44·1	6349	30999	2280	89·765	101·7
4	58·8	8465	41332	3040	119·687	135·6
5	73·5	10581	51665	3800	149·609	169·5
6	88·2	12698	61998	4560	179·531	203·4
7	102·9	14814	72331	5320	209·453	237·3
8	117·6	16930	82664	6080	239·374	271·2
9	132·3	19047	92997	6840	269·296	305·1
10	147·0	21163	103330	7600	299·218	339·0

Weights.

	Grammes.	Avoirdupois ounces.	Avoirdupois lbs.	Cwts.	Tons.	Grains Troy.
Milligramme	·001	...	...	...	...	·015
Centigramme	·01	...	...	...	...	·154
Decigramme	·1	...	...	...	...	1·543
Gramme ...	1	·035	·0022	...	...	15·432349
Decagramme	10	·35	·022	...	...	...
Hectogramme	100	3·527	·22046	...	...	...
Kilogramme	1,000	35·2739	2·2046	·019	·00098	...
Myriagramme	10,000	...	22·04	·1 68	·00984	...
Quintal ..	100,000	...	220·46	1 9684	·0984	...
Millier or Bar	1,000,000	...	2204·62	19·684	·984206	...

For weights corresponding with Avoir. and Troy, see page 18; also see pages 29, 31.

Dry and Fluid Measure.

	Litres.	Inches.	Feet.	Gallons.	Bushels.
Millilitre . .	001	·061	...	·00022	...
Centilitre .	·01	·61	...	·0022	...
Decilitre . .	·1	6·1	...	·022	·0027
Litre* . , .	1	61·02	·0353	.22	·0275
Decalitre .	10	061·28	·353	2·2	·276
Hectolitre .	100	...	3·53	22	2·751
Kilolitre† .	1,000	...	35·317	220	27·512
Myrialitre .	10,000	...	353·17	2200·967	27 5121

* Litre = ·22009668 gallons = a cubic decimetre.

† Kilolitre = a cubic metre.

1. The **Standard Pound Avoirdupois** is the weight, at the temperature of 62° Fahrenheit, and under the atmospheric pressure of 30 inches of mercury, in the latitude of London, and at or near the level of the sea, of a certain piece of platinum which is kept in the Exchequer Office at Westminster.

2. The **Standard Kilogramme** is the weight, at the temperature of the maximum density of water (about 4° Centigrade), and under the atmospheric pressure of 760 millimetres of mercury, in the latitude of Paris, of a certain piece of platinum which is kept in the French Archives. The use of weights founded on this standard is lawful in Britain, and a copy of it is kept in the Exchequer Office.

1. The **Standard Gallon** is the volume of 10 lbs. avoirdupois of pure water, at the temperature of 62° Fahrenheit, and under the atmospheric pressure of 30 inches of mercury. At that temperature the volume of water is 1·001118 times its minimum volume.

2. The **Standard Litre** is the volume of a kilogramme of pure water, at its temperature of maximum density (about 4° Centigrade), and under the atmospheric pressure of 760 millimetres of mercury. It was originally intended to be a cubic decimetre, but is actually somewhat greater.

Specific Gravity is the ratio of the weight of a given bulk of a given substance to the weight of the same bulk of pure water at a standard temperature. In Britain the standard temperature is 62° Fah. = 16°·67 Cent. In France it is the temperature of the maximum density of water = 3°·94 Cent. = 39°·1 Fah.

In rising from 39°·1 Fah. to 62° Fah., pure water expands in the ratio of 1·001118 to 1; but that difference is of no consequence in calculations of specific gravity for engineering purposes.

Rule I.—To find the specific gravity of a solid body that is heavier than water approximately, by experiment. Weigh it in air, and again weigh it immersed in pure water. Divide the weight in air by the loss of weight when immersed (or *buoyancy*); the quotient will be the specific gravity.

Rule II.—When the body is lighter than water, weigh it in air; then load it with a piece of a substance heavier than water, and large enough to make the light body sink, and weigh them in water together. Also weigh the heavy body separately, in air and in water. Subtract the buoyancy of the heavy body from the buoyancy of the two

bodies together; the remainder will be the buoyancy of the light body separately; by which its weight in air is to be divided as before.

RULE III.—To find approximately the specific gravity of a liquid; weigh some convenient solid body in air, in pure water, and in the given liquid; divide the buoyancy or loss of weight in the given liquid by the buoyancy in water; the quotient will be the required specific gravity.

RULE IV.—To find approximately the specific gravity of a solid body that is soluble in water; ascertain its buoyancy in some liquid which does not dissolve it, and whose specific gravity is known; divide the weight in air by the buoyancy in that liquid, and multiply the quotient by the specific gravity of the liquid.

The approximate character of all those rules arises from their not taking account of the buoyancy due to the pressure of the air, whether on the body weighed or on the weights; but for ordinary practical purposes the error so occasioned is immaterial.

The **Density** of a substance is either the number of units of *mass* in a unit of volume, in which case it is equal to the heaviness—or the ratio of the mass of a given volume of the substance to the mass of an equal volume of water, in which case it is equal to the specific gravity.

In its application to *gases* the term "Density" is often used to denote the ratio of the heaviness of a given gas to that of air, at the same temperature and pressure.

The **Bulkiness** of a substance is the number of units of volume which a unit of weight fills; and is the *reciprocal of the heaviness.*

In British measures bulkiness is most conveniently expressed in *cubic feet to the pound avoirdupois;* in French measures, in *cubic decimetres to the kilogramme.*

RULE V.—Given, the specific gravity of a substance; to find its bulkiness; divide the bulkiness of pure water by the specific gravity of the given substance.

In British measures 0·01602 cubic foot of pure water to the lb. is near enough for practical purposes; in French measures the bulkiness of pure water is 1.

The **Heaviness** of any substance is the weight of a unit of volume of it, in units of weight.

In British measures heaviness is most conveniently expressed in *pounds avoirdupois to the cubic foot, or in pound avoirdupois to the cubic inch;* in French measures, in *kilogrammes to the cubic decimetre, or in grammes to the cubic centimetre.*

SPECIFIC GRAVITIES (*Rankine, &c.*)

Or the Weight in Grammes of 1 Cubic Centimetre at 4° C.

1. *To find the weight of a cubic inch, multiply the specific gravity in the table by* ·0361, *the weight of a cubic inch of water.*

2. *To find the weight of a cubic foot, multiply the specific gravity in the table by* 62·4, *the weight of a cubic foot of water.*

Metals.

Iridium,	22·38
Platinum, rolled,	22·6
,, wire,	21·0
Gold,	19 to 19·6
Mercury, solid—40°,	15·6
,, at 0° C.,	13·6
,, at 15° C.,	13·58
,, at 100° C.,	13·37
Lead,	11·4
Silver,	10·5
Bismuth,	9·82
Copper, hammered,	8·9
,, wire,	8·8 to 8·9
,, cast,	8·6 to 8·7
Bronze gun metal,	8·4 to 8·7
Brass wire,	8·54
,, cast,	7·8 to 8·4
Nickel cast,	8·5
Steel,	7·8 to 7·9
Iron, wrought,	7·6 to 7·8
,, cast, average	7·1
Tin,	7·3 to 7·5
Zinc, rolled,	7·2
,, cast,	6·86
Antimony,	6·7
Selenium, black,	4·8
,, red,	4·5
Aluminium, rolled,	2·7
,, cast,	2·5
Magnesium,	1·74
Sodium,	0·97
Lithium,	0·59

Insulators.

Asbestos, starry,	3·0
Glass, flint,	2·93 to 3·0
,, white,	2·89
,, plate,	2·8
,, green,	2·7
Slate,	2·7 to 2·9
Marble,	2·66 to 2·8
Quartz,	2·66
Plaster Paris,	1·87 to 2·47
Sulphur,	2·0
Ivory,	1·82
Pitch,	1·6
Hooper's, I. R.,	1·18
Ebonite,	1·15
Oak, dry,	·7 to 1·0
Amber,	1·08
Boxwood,	·91 to 1·03
Guttapercha,	·97 to ·98
India-rubber, pure,	·93
Mahogany, Spanish,	·85
Pine, yellow,	·66

Liquids.

Mercury,	13·596
Sulphuric acid,	1·841
Nitric acid,	1·217
Water, sea,	1·026
,, pure,	1·0
Oil, linseed,	0·94
Naphtha,	0·848
Alcohol, pure,	·791
Ether,	·716

Comparison of Heads of Water in Feet, &c.—

One foot of water at 52°·3 Fah. =	62·4	lbs. on the square foot.
" "	0·4333	lbs. on the square inch.
" "	0·0295	atmosphere.
" "	0·8823	inch of mercury at 32°.
" "	773·	feet of air at 32°, and one atmosphere.

One lb. on the square foot, . 0·016026 foot of water at 52°·3 Fah.

One lb. on the square inch, .	= 2·308	feet of water.
One atmosphere of 29·922 inches of mercury, . . .	= 33·9	" "
One inch of mercury at 32°, .	= 1·1334	" "
One foot of air at 32°, and one atmosphere, ...	= 0·001294	" "
One foot of average sea water,	= 1·026	foot of pure water.

A *ton* of sea-water = 35 cubic feet = $218\frac{1}{4}$ gallons nearly, = 991·04 litres.

Temperature, or, Intensity of Heat.—

STANDARD POINTS—	Fahrenheit.	Centigrade.	Reaumur.
Boiling point of water under one atmosphere =	212°	100°	80°
Melting point of ice, .	32°	0°	0°
(Absolute zero; known by theory only, . . . = about	−461°·2	−274°	−219°·2)

9° Fahrenheit = 5° Centigrade = 4° Reaumur.

$$\text{Temp. Fah.} = \frac{9}{5}\text{Temp. Cent.} + 32^\circ = \frac{9}{4}\text{Temp. Reau.} + 32^\circ$$

$$\text{Temp. Cent.} = \frac{5}{9}(\text{Temp. Fah.} - 32^\circ) = \frac{5}{4}\text{Temp. Reau.}$$

$$\text{Temp. Reau.} = \frac{4}{9}(\text{Temp. Fah.} - 32^\circ) = \frac{4}{5}\text{Temp. Cent.}$$

One French unit of heat or *Calorie* = 3·96832 British units.
One British unit of heat . . . . = 0·251996 French unit.

Table of Comparison of Different Thermometers.

Fah.	Reau.	Cent.	Fah.	Reau.	Cent.	Fah.	Reau.	Cent.
212	80·0	100·0	173	62·6	78·3	134	45·3	56 6
211	79·5	99·4	172	62·2	77 7	133	44·8	56·1
210	79·1	98·8	171	61·7	77·2	132	44·4	55·5
209	78·6	98·3	170	61 3	76·6	131	44 0	55·0
208	78·2	97·7	169	60·8	76·1	130	43·5	54·4
207	77·7	97·2	168	60·4	75·5	129	43·1	53·8
206	77·3	96 6	167	60·0	75·0	128	42·6	53 3
205	76·8	96·1	166	59·5	74·4	127	42·2	52·7
204	76·4	95·5	165	59 1	73 8	126	41·7	52·2
203	76·0	95 0	164	58 6	73 3	125	41·3	51·6
202	75·5	94·4	163	58·2	72·7	124	40·8	51·1
201	75·1	93·8	162	57·7	72·2	123	40·4	50 5
200	74·6	93·3	161	57·3	71·6	122	40·0	50·0
199	74·2	92 7	160	56·8	71·1	121	39·5	49·4
198	73·7	92 2	159	56·4	70 5	120	39 1	48·8
197	73·3	91·6	158	56·0	70·0	119	38·6	48·3
196	72·8	91·1	157	55 5	69·4	118	38·2	47·7
195	72·4	90·5	156	55 1	68·8	117	37·7	47·2
194	72·0	90·0	155	54·6	68 3	116	37·3	46·6
193	71·5	89·4	154	54 2	67 7	115	36 8	46·1
192	71·1	88·8	153	53 7	67·2	114	36·4	45·5
191	70·6	88·3	152	53·3	66·6	113	36·0	45·0
190	70·2	87·7	151	52·8	66·1	112	35·5	44·4
189	69·7	87·2	150	52·4	65·5	111	35·1	43 8
188	69·3	86·6	149	52·0	65·0	110	34·6	43·3
187	68·8	86·1	148	51·5	64·4	109	34·2	42·7
186	68·4	85 5	147	51·1	63·8	108	33·7	42 2
185	68·0	85·0	146	50 6	63·3	107	33·3	41 6
184	67·5	84·4	145	50·2	62·7	106	32·8	41·1
183	67·1	83·8	144	49·7	62·2	105	32·4	40·5
182	66·6	83·3	143	49·3	61·6	104	32·0	40·0
181	66·2	82·7	142	48·8	61·1	103	31·5	39 4
180	65·7	82·2	141	48·4	60·5	102	31·1	38·8
179	65·3	81·6	140	48·0	60 0	101	30·6	38 3
178	64 8	81·1	139	47·5	59·4	100	30·2	37·7
177	64·4	80·5	138	47 1	58·8	99	29·7	37·2
176	64·0	80·0	137	46 6	58·3	98	29·3	36·6
175	63·5	79·4	136	46·2	57·7	97	28 8	36·1
174	63·1	78·8	135	45·7	57·2	96	28·4	35·5
Fah.	Reau.	Cent.	Fah.	R eau	Cent.	Fah.	Reau.	Cent.

Table of Comparison of Different Thermometers.

Fah.	Reau.	Cent.	Fah.	Reau.	Cent.	Fah.	Reau.	Cent.
95	28·0	35·0	56	10·6	13·3	17	—6·6	— 8·3
94	27·5	34·4	55	10·2	12·7	16	—7·1	— 8·8
93	27·1	33·8	54	9·7	12·2	15	—7·5	— 9·5
92	26·6	33·3	53	9·3	11·6	14	—8·0	—10·0
91	26·2	32·7	52	8·8	11·1	13	—8·4	—10·5
90	25·7	32·2	51	8·4	10·5	12	—8·8	—11·1
89	25·3	31·6	50	8·0	10·0	11	—9·3	—11·6
88	24·8	31·1	49	7·5	9·4	10	—9·7	—12·2
87	24·4	30·5	48	7·1	8·8	9	—10·2	—12·7
86	24·0	30·0	47	6·6	8·3	8	—10·6	—13·3
85	23·5	29·4	46	6·2	7·7	7	—11·1	—13·8
84	23·1	28·8	45	5·7	7·2	6	—11·5	—14·4
83	22·6	28·3	44	5·3	6·6	5	—12·0	—15·0
82	22·2	27·7	43	4·8	6·1	4	—12·4	—15·5
81	21·7	27·2	42	4·4	5·5	3	—12·8	—16·1
80	21·3	26·6	41	4·0	5·0	2	—13·3	—16·6
79	20·8	26·1	40	3·5	4·4	1	—13·7	—17·2
78	20·4	25·5	39	3·1	3·8	0	—14·2	—17·7
77	20·0	25·0	38	2·6	3·3	—1	—14·6	—18·3
76	19·5	24·4	37	2·2	2·7	—2	—15·1	—18·8
75	19·1	23·8	36	1·7	2·2	—3	—15·5	—19·4
74	18·6	23·3	35	1·3	1·6	—4	—16·0	—20·0
73	18·2	22·7	34	0·8	1·1	—5	—16·4	—20·5
72	17·7	22·2	33	0·4	0·5	—6	—16·8	—21·1
71	17·3	21·6	32	0·0	0·0	—7	—17·3	—21·6
70	16·8	21·1	31	—0·4	—0·5	—8	—17·7	—22·2
69	16·4	20·5	30	—0·8	—1·1	—9	—18·2	—22·7
68	16·0	20·0	29	—1·3	—1·6	—10	—18·6	—23·3
67	15·5	19·4	28	—1·7	—2·2	—11	—19·1	—23·8
66	15·1	18·8	27	—2·2	—2·7	—12	—19·5	—24·4
65	14·6	18·3	26	—2·6	—3·3	—13	—20·0	—25·0
64	14·2	17·7	25	—3·1	—3·8	—14	—20·4	—25·5
63	13·7	17·2	24	—3·5	—4·4	—15	—20·8	—26·1
62	13·3	16·6	23	—4·0	—5·0	—16	—21·3	—26·6
61	12·8	16·1	22	—4·4	—5·5	—17	—21·7	—27·2
60	12·4	15·5	21	—4·8	—6·1	—18	—22·2	—27·7
59	12·0	15·0	20	—5·3	—6·6	—19	—22·6	—28·3
58	11·5	14·4	19	—5·7	—7·2	—20	—23·1	—28·8
57	11·1	13·8	18	—6·2	—7·7			
Fah.	Reau.	Cent.	Fah.	Reau.	Cent.	Fah.	Reau.	Cent.

Measures of Time.

Sidereal Day.—The standard unit of time is the Sidereal Day, being the period in which the earth turns once round on its axis. It is divided into sidereal hours, minutes, and seconds; but these measures of time are used by astronomers only.

Mean Solar Time.—A second is the time of one swing of a pendulum adjusted so as to make 86,164·09 swings in a sidereal day. Seconds are usually subdivided decimally.

One mean solar day = 24 hours = 1,440 minutes = 86,400 seconds = 1·00273791 sidereal day.

Relation between Time and Longitude.—At any given instant the mean solar time at two stations differs by an amount proportional to their difference of longitude, the time at the eastern station being the earlier.

Corresponding Differences.

Longitude.	Time.	Longitude.	Time.
15″	1 second.	75°	5 hours.
1′	4 seconds.	90	6 ,,
15′	1 minute.	105	7 ,,
1°	4 minutes.	120	8 ,,
15°	1 hour.	135	9 ,,
30	2 hours.	150	10 ,,
45	3 ,,	165	11 ,,
60	4 ,,	180	12 ,,

To show the exact date of any event, the meridian at which the time is reckoned must be specified.

It is customary for civil and commercial pur-

poses to reckon time at all places throughout Britain as for the meridian of Greenwich; local mean solar time being found for scientific purposes, when required, by calculation.

Useful Numbers.

$$\pi = 3{\cdot}1416 = \frac{22}{7}$$

$$2\pi = 6{\cdot}2832$$

$$4\pi = 12{\cdot}5664$$

$$\pi^2 = 9{\cdot}8696$$

$$\sqrt{\pi} = 1{\cdot}77245$$

$$\frac{1}{\pi} = 0{\cdot}31831$$

$$\frac{1}{\sqrt{\pi}} = 0{\cdot}56419$$

$$\text{Log. } \pi = 0{\cdot}4971499$$

Area of a circle $= \pi r^2 = \frac{\pi}{4} d^2 = {\cdot}7854\, d^2$.

Circumference of a circle $= 2\pi r = \pi d$.

Surface of a sphere $= 4\pi r^2 = \pi d^2$.

Volume of a sphere $= \frac{4}{3}\pi r^3$.

Angle for which arc equal radius
$= 57^\circ{\cdot}2958 = 3437'{\cdot}75 = 206265''$

$g = 32{\cdot}2$ ft. per sec. per sec., *i.e.*, $981{\cdot}17$ cms. per sec. per sec.

See p. 454 for longarithmic and algebraic constants.

Falling Bodies.

T = Time of falling in seconds.

S = Space fallen through in feet.

V = Velocity in feet per second acquired in time, T, or space, S.

$$V = Tg = T \times 32{\cdot}2$$

$$= \sqrt{S \cdot 2g} = 8{\cdot}025\sqrt{S}$$

$$\therefore\ S = \frac{T^2 g}{2} = T^2 \times 16{\cdot}1$$

Pendulum.

l = Length of pendulum in inches.

T = Time of one oscillation in seconds.

N = Number of oscillations per minute.

g = Gravitation value, 386·4 inches.

$$T = \pi\sqrt{\frac{l}{g}}$$

$$N = \frac{60 \text{ seconds}}{T} = \frac{60}{\pi\sqrt{\frac{l}{g}}}$$

$$l = g\left(\frac{T}{\pi}\right)^2$$

l = 39·138 inches = 99·410 cms., in the latitude of London, when T = 1, *i.e.*, for the seconds pendulum.

Areas of Small Circles, advancing by Decimals.

Diam.	Areas.				
	·000	·001	·002	·003	·004
·000	0	·0000008	·0000031	·0000071	·0000126
·010	·0000785	·0000950	·0001131	·0001327	·0001539
·020	·0003142	·0003464	·0003801	·0004155	·0004524
·030	·0007069	·0007548	·0008043	·0008553	·0009079
·040	·0012566	·0013203	·0138559	·0014522	·0015205
·050	·0019635	·0020428	·0021237	·0022062	·0022902
·060	·0028274	·0029225	·0030191	·0031172	·0032170
·070	·0038484	·0039592	·0040715	·0041854	·0043008
·080	·0050276	·0051530	·0052810	·0054106	·0055418
·090	·0063617	·0065039	·0066476	·0067929	·0069398
	·005	·006	·007	·008	·009
·000	·0000196	·0000283	·0000385	·0000503	·0000639
·010	·0001767	·0002016	·0002270	·0002565	·0002835
.020	·0004909	·0005309	·0005726	·0006158	·0006605
·030	·0009621	·0010179	·0010752	·0011341	·0011946
·040	·0015904	·0016619	·0017349	·0018096	·0018857
·050	·0023758	·0024630	·0025517	·0026421	·0027340
·060	·0033183	·0034212	·0035257	·0036317	·0037393
·070	·0044479	·0045365	·0046566	·0047784	·0049017
·080	·0056745	·0058088	·0059447	·0060821	·0062211
·090	·0070882	·0072382	·0073898	·0075430	·0076977

Areas of Small Circles.

Diam.	·00	.01	·02	·03	·04	·05	·06	·07	·08	·09
·0	·0	·000078	·00031	·0007	·00125	·00196	·00283	·00385	·00503	·00636
·1	·0078	·0095	·0113	·0133	·0154	·0177	·0201	·0227	·0255	·0283
·2	·0314	·03464	·038	·0415	·0452	·0491	·0531	·0572	·0616	·066
·3	·0706	·0755	·0804	·0855	·0908	·0962	·1018	·1075	·1134	·1195
·4	·1256	·132	·1385	·1542	·1520	·1590	·1662	·1735	·181	·1886
·5	1963	·2043	·2124	·2206	·2290	·2376	2463	·2552	·2642	·2734
·6	·2827	·2922	·3014	·3117	·3217	·3318	·3421	·3526	·3632	·3739
·7	3848	·3959	·4071	·4185	·4301	·4418	·4536	·4657	·4778	·4902
·8	·5026	·5153	·5281	·5411	·5542	·5674	·5809	·5945	·6082	·6221
·9	·6362	·6504	·6648	·6793	·694	·7088	·7238	·739	·7543	·7698

Areas of Circles, advancing by 10ths.

Diam.	Areas.										Diam.
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	
0	·0	·0078	·0314	·0706	·1256	·1963	·2827	·3848	·5026	·6361	0
1	·7854	·9503	1·1309	1·3273	1·5393	1·7671	2·0106	2·2698	2·5446	2 8352	1
2	3·1416	3·4636	3·8013	4·1547	4·5239	4·9087	5·3093	5·7255	6 1575	6·6052	2
3	7·0686	7·5476	8·0424	8·5530	9·0792	9 6211	10·1787	10·7521	11·3411	11·9459	3
4	12 5664	13·2025	13·8544	14 5220	15·2053	15·9043	16·6190	17·3494	18·0951	18·8574	4
5	19·6350	20·4282	21·2372	22·0618	22·9022	23·7583	24·6301	25·5176	26·4208	27·3397	5
6	28·2744	29·2247	30·1907	31·1725	32·1699	33·1831	34·2120	35·2566	36·3168	37·3928	6
7	38·4846	39·5920	40·7151	41·8539	43·0085	44·1787	45·3647	46·5663	47·7837	49·0168	7
8	50·2656	51·5300	52·8102	54 1062	55·4178	56·7451	58·0881	59·4469	60·8213	62·2115	8
9	63·6174	65·0389	66·4762	67·9292	69·3979	70·8823	72·3824	73·8982	75·4298	76·9770	9
10	78·5400	80·1186	81·7130	83·3230	84·9488	86·5903	88·2475	89·9204	91·6090	93·3133	10
11	95·0334	96·7691	98·5205	100·287	102·070	103·869	105·683	107·513	109·359	111·220	11
12	113 097	114·990	116·898	118·823	120·763	122·718	124·690	126·677	128·679	130·698	12
13	132·732	134·782	136·848	138·929	141·026	143·139	145·267	147·411	149·571	151·747	13
14	153·938	156·145	158·368	160·606	162·860	165·130	167·415	169·717	172·034	174·366	14
15	176·715	179·079	181·458	183·854	186·265	188·692	191·134	193·593	196·067	198·556	15
16	201·062	203·583	206·120	208·672	211·241	213·825	216·424	219·040	221·671	224·318	16
17	226·980	229·658	232·352	235·062	237·787	240·528	243·285	246·057	248·846	251·650	17
18	254·469	257·304	260·155	263·022	265·905	268·803	271·716	274·646	277·591	280·552	18
19	283 529	286·521	289·529	292·553	295·593	298·648	301·719	304·805	307·908	311·026	19
20	314·160	317·309	320·474	323·655	326·852	330·064	333·292	336·536	339·795	343 070	20
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	

AREAS OF CIRCLES, ADVANCING BY 10THS—*Continued.*

Diam.	Areas.										Diam.
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	
21	346·361	349·667	352·990	356·328	359·681	363·051	366·436	369·837	373·253	376·685	21
22	380·133	383·597	387·076	390·571	394·082	397·608	401·150	404·708	408·282	411·871	22
23	415·476	419·097	422·733	426·385	430·053	433·737	437·436	441·151	444·881	448·628	23
24	452·390	456·168	459·961	463·770	467·595	471·436	475·292	479·164	483·052	486·955	24
25	490·875	494·809	498·760	502·726	506·708	510·706	514·719	518·748	522·793	526·854	25
26	530·930	535·022	539·129	543·253	547·392	551·547	555·717	559·903	564·105	568·323	26
27	572·556	576·805	581·070	585·350	589·646	593·958	598·286	602·629	606·988	611·363	27
28	615·753	620·159	624·581	629·019	633·472	637·941	642·425	646·926	651·442	655·973	28
29	660·521	665·084	669·663	674·258	678·868	683·494	688·136	692·793	697·466	702·155	29
30	706·860	711·580	716·316	721·067	725·835	730·618	735·417	740·231	745·061	749·907	30
31	754·769	759·646	764·539	769·448	774·372	779·313	784·268	789·240	794·227	799·230	31
32	804·249	809·284	814·334	819·399	824·481	829·578	834·691	839·820	844·964	850·124	32
33	855·300	860·492	865·699	870·922	876·160	881·415	886·685	891·970	897·272	902·589	33
34	907·922	913·270	918·635	924·011	929·410	934·822	940·249	945·692	951·150	956·625	34
35	962·115	967·620	973·142	978·679	984·231	989·800	995·384	1000·98	1006·60	1012·23	35
36	1017·87	1023·54	1029·21	1034·91	1040·62	1046·34	1052·09	1057·84	1063·62	1069·40	36
37	1075·21	1081·03	1086·86	1092·71	1098·58	1104·46	1110·36	1116·28	1122·21	1128·15	37
38	1134·11	1140·09	1146·08	1152·09	1158·11	1164·15	1170·21	1176·28	1182·37	1188·47	38
39	1194·59	1200·72	1206·87	1213·04	1219·22	1225·42	1231·63	1237·86	1244·10	1250·36	39
40	1256·64	1262·93	1269·23	1275·56	1281·89	1288·25	1294·62	1301·00	1307·40	1313·82	40
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	

AREAS OF CIRCLES, ADVANCING BY 10THS—*Continued.*

Diam.	Areas.										Diam.
	·0	·1	2·	·3	·4	·5	·6	·7	·8	·9	
41	1320·25	1326·70	1333·16	1339·64	1346·14	1352·65	1359·18	1365·72	1372·28	1378·85	41
42	1385·44	1392·05	1398·67	1405·30	1411·96	1418·62	1425·31	1432·01	1438·72	1445·45	42
43	1452·20	1458·96	1465·74	1472·53	1479·34	1486·17	1493·01	1499·87	1506·74	1513·62	43
44	1520·53	1527·45	1534·38	1541·33	1548·30	1555·28	1562·28	1569·29	1576·32	1583·37	44
45	1590·43	1597·51	1604·60	1611·71	1618·83	1625·97	1633·12	1640·30	1647·48	1654·68	45
46	1661·90	1669·13	1676·37	1683·65	1690·93	1698·23	1705·54	1712·87	1720·21	1727·57	46
47	1734·94	1742·33	1749·74	1757·16	1764·60	1772·05	1779·52	1787·01	1794·51	1802·02	47
48	1809·56	1817·10	1824·67	1832·25	1839·84	1847·45	1855·08	1862·72	1870·38	1878·05	48
49	1885·74	1893·45	1901·17	1908·90	1916·65	1924·42	1932·20	1940·00	1947·82	1955·65	49
50	1963·50	1971·36	1979·23	1987·13	1995·04	2002·96	2010·90	2018·86	2026·83	2034·82	50
51	2042·82	2050·84	2058·87	2066·92	2074·99	2083·07	2091·17	2099·28	2107·41	2115·56	51
52	2123·72	2131·89	2140·08	2148·29	2156·51	2164·75	2173·01	2181·28	2189·56	2197·87	52
53	2206·18	2214·52	2222·87	2231·23	2239·61	2248·01	2256·42	2264·85	2273·29	2281·75	53
54	2290·22	2298·71	2307·22	2315·74	2324·28	2332·83	2341·40	2349·98	2358·58	2367·20	54
55	2375·83	2384·48	2393·14	2401·82	2410·51	2419·22	2427·95	2436·69	2445·45	2454·22	55
56	2463·01	2471·81	2480·63	2489·47	2498·32	2507·19	2516·07	2524·97	2533·88	2542·81	56
57	2551·76	2560·72	2569·70	2578·69	2587·70	2596·72	2605·76	2614·12	2623·89	2632·98	57
58	2642·08	2651·20	2660·33	2669·48	2678·65	2687·83	2697·03	2706·24	2715·47	2724·71	58
59	2733·97	2743·25	2752·54	2761·85	2771·17	2780·51	2789·86	2799·23	2808·62	2818·02	59
60	2827·44	2836·87	2846·32	2855·78	2865·26	2874·76	2884·26	2893·79	2903·34	2912·89	60
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	

AREAS OF CIRCLES, ADVANCING BY 10THS—*Continued.*

Diam.	Areas.										Diam.
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	
61	2922·47	2932·06	2941·66	2951·28	2960·92	2970·57	2980·24	2989·93	2999·63	3009·34	61
62	3019·07	3028·82	3038·58	3048·36	3058·15	3067·96	3077·79	3087·63	3097·49	3107·36	62
63	3117·25	3127·15	3137·07	3147·01	3156·96	3166·92	3176·91	3186·90	3196·92	3206·95	63
64	3216·99	3227·05	3237·13	3247·22	3257·33	3267·46	3277·59	3287·75	3997·92	3308·11	64
65	3318·31	3328·53	33·3876	3349·01	3359·28	3369·56	3379·85	3390·17	3400·49	3410·84	65
66	3421·20	3431·57	3441·96	3452·37	3462·79	3473·23	3483·68	3494·16	3504·64	3515·14	66
67	3525·66	3536·19	3546·74	3557·30	3567·88	3578·47	3589·08	3599·71	3610·35	3621·01	67
68	3631·68	3642·37	3653·08	3663·80	3674·54	3685·29	3696·06	3706·84	3717·64	3728·45	68
69	3739·28	3750·13	3760·99	3771·87	3782·76	3793·67	3804·60	3815·54	3826·50	3837·47	69
70	3848·46	3859·46	3870·48	3881·51	3892·56	3903·63	3914·71	3925·81	3936·92	3948·05	70
71	3959·20	3970·36	3981·53	3992·73	4003·93	4015·16	4026·40	4037·65	4048·92	4060·21	71
72	4071·51	4082·83	4094·16	4105·51	4116·87	4128·25	4139·65	4151·06	4162·49	4173·93	72
73	4185·39	4196·87	4208·36	4219·86	4231·38	4242·92	4254·48	4266·04	4277·63	4289·23	73
74	4300·85	4312·48	4324·12	4335·79	4347·47	4359·16	4370·87	4382·60	4394·34	4406·10	74
75	4417·87	4429·66	4441·46	4453·28	4465·12	4476·97	4488·84	4500·72	4512·62	4524·54	75
76	4536·47	4548·41	4560·37	4572·35	4584·35	4596·35	4608·38	4620·42	4632·47	4644·54	76
77	4656·63	4668·73	4680·85	4692·99	4705·14	4717·30	4729·49	4741·68	4753·96	4766·12	77
78	4778·37	4790·63	4802·90	4815·20	4827·50	4839·83	4852·16	4864·52	4876·89	4889·27	78
79	4901·68	4914·09	4926·53	4938·98	4951·44	4963·92	4976·42	4988·93	5001·45	5014·00	79
80	5026·56	5039·13	5051·72	5064·32	5076·95	5089·58	5102·24	5114·90	5127·59	5140·29	80
	.0	·1	·2	·3	·4	·5	·6	·7	·8	·9	

AREAS OF CIRCLES, ADVANCING BY 10THS—*Continued.*

Diam.	Areas.										Diam.
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	
81	5153·00	5165·74	5178·48	5191·25	5204·02	5216·82	5229·63	5242·45	5255·29	5268·15	81
82	5281·02	5293·91	5306·82	5319·74	5332·67	5345·62	5358·59	5371·57	5384·57	5397·59	82
83	5410·62	5423·66	5436·72	5449·80	5462·89	5476·00	5489·12	5502·26	5515·42	5528·59	83
84	5541·78	5554·98	5568·20	5581·43	5594·68	5607·95	5621·23	5634·53	5647·84	5661·17	84
85	5674·51	5687·87	5701·25	5714·64	5728·04	5741·47	5754·90	5768·36	5781·83	5795·31	85
86	5808·81	5822·33	5835·86	5849·41	5862·97	5876·55	5890·15	5903·76	5917·39	5931·03	86
87	5944·69	5958·36	5972·05	5985·76	5999·48	6013·21	6026·97	6040·73	6054·52	6068·32	87
88	6082·13	6095·96	6109·81	6123·67	6137·55	6151·44	6165·35	6179·28	6193·22	6207·18	88
89	6221·15	6235·14	6249·14	6263·16	6277·19	6291·20	6305·31	6319·39	6333·49	6347·61	89
90	6361·74	6375·88	6390·04	6404·22	6418·41	6432·62	6446·84	6461·08	6475·34	6489·61	90
91	6503·89	6518·19	6532·51	6546·85	6561·20	6575·56	6589·94	6604·34	6618·75	6633·18	91
92	6647·62	6662·08	6676·55	6691·05	6705·55	6720·07	6734·61	6749·16	6763·73	6778·32	92
93	6792·92	6807·54	6822·17	6836·82	6851·48	6866·16	6880·85	6895·56	6910·29	6925·03	93
94	6939·79	6954·56	6969·35	6984·16	6998·98	7013·81	7028·67	7043·53	7058·42	7073·32	94
95	7088·23	7103·16	7118·11	7133·07	7148·05	7163·04	7178·05	7193·07	7208·11	7223·17	95
96	7238·24	7253·33	7268·43	7283·55	7298·69	7313·84	7329·00	7344·18	7359·38	7374·59	96
97	7389·82	7405·07	7420·33	7435·60	7450·90	7466·20	7481·53	7496·87	7512·22	7527·59	97
98	7542·98	7558·38	7573·80	7589·23	7604·68	7620·14	7635·62	7651·19	7666·63	7682·16	98
99	7697·70	7713·26	7728·83	7744·42	7760·03	7775·65	7791·29	7806·94	7822·61	7838·29	99
100	7854·00	7869·71	7885·44	7901·19	7916·95	7932·73	7948·53	7964·34	7980·16	7996·00	100
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	

Circumferences of Circles.

Diam.	Circumferences.										Diam.
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	
0	·00	·31	·62	·94	1·25	1·57	1·88	2·19	2·51	2·82	0
1	3·14	3·45	3·77	4·08	4·39	4·71	5·02	5·34	5·65	5·96	1
2	6·28	6·59	6·91	7·22	7·53	7·85	8·16	8·48	8·79	9·11	2
3	9·42	9·74	10·05	10·36	10·68	10·99	11·30	11·62	11·93	12·25	3
4	12·56	12·88	13·19	13·50	13·82	14·13	14·45	14·76	15·08	15·39	4
5	15·70	16·02	16·33	16·65	16·96	17·27	17·59	17·90	18·22	18·53	5
6	18·84	19·16	19·47	19·79	20·10	20·42	20·73	21·04	21·36	21·67	6
7	21·99	22·30	22·61	22·93	23·24	23·56	23·87	24·19	24·50	24·81	7
8	25·13	25·44	25·76	26·07	26·38	26·70	27·01	27·33	27·64	27·96	8
9	28·27	28·58	28·90	29·21	29·53	29·84	30·15	30·47	30·78	31·10	9
10	31·41	31·73	32·04	32·35	32·67	32·98	33·30	33·61	33·92	34·24	10
11	34·55	34·87	35·18	35·50	35·81	36·12	36·44	36·75	37·07	37·38	11
12	37·69	38·01	38·32	38·64	38·95	39·27	39·58	39·89	40·21	40·52	12
13	40·84	41·15	41·46	41·78	42·09	42·41	42·72	43·03	43·35	43·66	13
14	43·98	44·29	44·61	44·92	45·23	45·55	45·86	46·18	46·49	46·80	14
15	47·12	47·43	47·75	48·06	48·38	48·69	49·00	49·32	49·63	49·95	15
16	50·26	50·57	50·89	51·20	51·52	51·83	52·15	52·46	52·78	53·09	16
17	53·40	53·72	54·03	54·35	54·65	54·97	55·29	55·60	55·92	56·23	17
18	56·54	56·86	57·17	57·49	57·80	58·11	58·43	58·74	59·06	59·37	18
19	59·69	60·00	60·31	60·63	60·94	61·26	61·57	61·88	62·20	62·51	19
20	62·83	63·14	63·46	63·77	64·08	64·40	64·71	65·03	65·34	65·65	20
21	65·97	66·28	66·60	66·91	67·22	67·54	67·85	68·17	68·48	68·80	21
22	69·11	69·42	69·74	70·05	70·37	70·68	71·00	71·31	71·62	71·94	22
23	72·25	72·57	72·88	73·19	73·51	73·82	74·14	74·45	74·76	75·08	23
24	75·39	75·71	76·02	76·34	76·65	76·96	77·28	77·59	77·91	78·22	24
25	78·54	78·85	79·16	79·48	79·79	80·11	80·42	80·73	81·05	81·36	25
26	81·68	81·99	82·30	82·62	82·93	83·25	83·56	83·88	84·19	84·50	26
27	84·82	85·13	85·45	85·76	86·07	86·39	86·70	87·02	87·33	87·65	27
28	87·96	88·27	88·59	88·90	89·22	89·53	89·84	90·16	90·47	90·79	28
29	91·10	91·42	91·73	92·04	92·36	92·67	92·99	93·30	93·61	93·93	29
30	94·24	94·56	94·87	95·19	95·50	95·81	96·13	96·44	96·76	97·07	30
31	97·38	97·70	98·01	98·33	98·64	98·96	99·27	99·58	99·90	100·2	31
32	100·5	100·8	101·1	101·4	101·7	102·1	102·4	102·7	103·0	103·3	32
33	103·6	103·9	104·3	104·6	104·9	105·2	105·5	105·8	106·1	106·5	33
34	106·8	107·1	107·4	107·7	108·0	108·3	108·6	109·0	109·3	109·6	34
35	109·9	110·2	110·5	110·8	111·2	111·5	111·8	112·1	112·4	112·7	35

Circumferences of Circles—*Continued.*

Diam.	Circumferences.										Diam.
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	
36	113·0	113·4	113·7	114·0	114·3	114·6	114·9	115·2	115·6	115·9	36
37	116·2	116·5	116·8	117·1	117·4	117·8	118·1	118·4	118·7	119·0	37
38	119·3	119·6	120·0	120·3	120·6	120·9	121·2	121·5	121·8	122·2	38
39	122·5	122·8	123·1	123·4	123·7	124·0	124·4	124·7	125·0	125·3	39
40	125·6	125·9	126·2	126·6	126·9	127·2	127·5	127·8	128·1	128·4	40
41	128·8	129·1	129·4	129·7	130·0	130·3	130·6	131·0	131·3	131·6	41
42	131·9	132·2	132·5	132·8	133·2	133·5	133·8	134·1	134·4	134·7	42
43	135·0	135·4	135·7	136·0	136·3	136·6	136·9	137·2	137·6	137·9	43
44	138·2	138·5	138·8	139·1	139·4	139·8	140·1	140·4	140·7	141·0	44
45	141·3	141·6	142·0	142·3	142·6	142·9	143·2	143·5	143·9	144·2	45
46	144·5	144·8	145·1	145·4	145·7	146·0	146·3	146·7	147·0	147·3	46
47	147·6	147·9	148·3	148·6	148·9	149·2	149·5	149·8	150·1	150·4	47
48	150·7	151·1	151·4	151·7	152·0	152·3	152·6	152·9	153·3	153·6	48
49	153·9	154·2	154·5	154·8	155·1	155·5	155·8	156·1	156·4	156·7	49
50	157·0	157·3	157·7	158·0	158·3	158·6	158·9	159·2	159·5	159·9	50
51	160·2	160·5	160·8	161·1	161·4	161·7	162·1	162·4	162·7	163·0	51
52	163·3	163·6	163·9	164·3	164·6	164·9	165·2	165·5	165·8	166·1	52
53	166·5	166·8	167·1	167·4	167·7	168·0	168·3	168·7	169·0	169·3	53
54	169·6	169·9	170·2	170·5	170·9	171·2	171·5	171·8	172·1	172·4	54
55	172·7	173·1	173·4	173·7	174·0	174·3	174·6	174·9	175·3	175·6	55
56	175·9	176·2	176·5	176·8	177·1	177·5	177·8	178·1	178·4	178·7	56
57	179·0	179·3	179·7	180·0	180·3	180·6	180·9	181·2	181·5	181·9	57
58	182·2	182·5	182·8	183·1	183·4	183·7	184·0	184·4	184·7	185·0	58
59	185·3	185·6	185·9	186·2	186·6	186·9	187·2	187·5	187·8	188·1	59
60	188·4	188·8	189·1	189·4	189·7	190·0	190·3	190·6	191·0	191·3	60
61	191·6	191·9	192·2	192·5	192·8	193·2	193·5	193·8	194·1	194·4	61
62	194·7	195·0	195·4	195·7	196·0	196·3	196·6	196·9	197·2	197·6	62
63	197·9	198·2	198·5	198·8	199·1	199·4	199·8	200·1	200·4	200·7	63
64	201·0	201·3	201·6	202·0	202·3	202·6	202·9	203·2	203·5	203·8	64
65	204·2	204·5	204·8	205·1	205·4	205·7	206·0	206·4	206·7	207·0	65
66	207·3	207·6	207·9	208·2	208·6	208·9	209·2	209·5	209·8	210·1	66
67	210·4	210·8	211·1	211·4	211·7	212·0	212·3	212·6	213·0	213·3	67
68	213·6	213·9	214·2	214·5	214·8	215·1	215·5	215·8	216·1	216·4	68
69	216·7	217·0	217·3	217·7	218·0	218·3	218·6	218·9	219·2	219·5	69
70	219·9	220·2	220·5	220·8	221·1	221·4	221·7	222·1	222·4	222·7	70

Circumferences of Circles—*Continued.*

Diam.	Circumferences.										Diam.
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	
71	223·0	223·3	223·6	223·9	224·3	224·6	224·9	225·2	225·5	225·8	71
72	226·1	226·5	226·8	227·1	227·4	227·7	228·0	228·3	228·7	229·0	72
73	229·3	229·6	229·9	230·2	230·5	230·9	231·2	231·5	231·8	232·1	73
74	232·4	232·7	233·1	233·4	233·7	234·0	234·3	234·6	234·9	235·3	74
75	235·6	235·9	236·2	236·5	236·8	237·1	237·5	237·8	238·1	238·4	75
76	238·7	239·0	239·3	239·7	240·0	240·3	240·6	240·9	241·2	242·5	76
77	241·9	242·2	242·5	242·8	243·1	243·4	243·7	244·1	244·4	244·7	77
78	245·0	245·3	245·6	245·9	246·3	246·6	246·9	247·2	247·5	247·8	78
79	248·1	248·5	248·8	249·1	249·4	249·7	250·0	250·3	250·6	251·0	79
80	251·3	251·6	251·9	252·2	252·5	252·8	253·2	253·5	253·8	254·1	80
81	254·4	254·7	255·0	255·4	255·7	256·0	256·3	256·6	256·9	257·2	81
82	257·6	257·9	258·2	258·5	258·8	259·1	259·4	259·8	260·1	260·4	82
83	260·7	261·0	261·3	261·6	262·0	262·3	262·6	262·9	263·2	263·5	83
84	263·8	264·2	264·5	264·8	265·1	265·4	265·7	266·0	266·4	266·7	84
85	267·0	267·3	267·6	267·9	268·2	268·6	268·9	269·2	269·5	269·8	85
86	270·1	270·4	270·8	271·1	271·4	271·7	272·0	272·3	272·6	273·0	86
87	273·3	273·6	273·9	274·2	274·5	274·8	275·2	275·5	275·8	276·1	87
88	276·4	276·7	277·0	277·4	277·7	278·0	278·3	278·6	278·9	279·2	88
89	279·6	279·9	280·2	280·5	280·8	281·1	281·4	281·8	282·1	282·4	89
90	282·7	283·0	283·3	283·6	284·0	284·3	284·6	284·9	285·2	285·5	90
91	285·8	286·1	286·5	286·8	287·1	287·4	287·7	288·0	288·3	288·7	91
92	289·0	289·3	289·6	289·9	290·2	290·5	290·9	291·2	291·5	291·8	92
93	292·1	292·4	292·7	293·1	293·4	293·7	294·0	294·3	294·6	294·9	93
94	295·3	295·6	295·9	296·2	296·5	296·8	297·1	297·5	297·8	298·1	94
95	298·4	298·7	299·0	299·3	299·7	300·0	300·3	300·6	300·9	301·2	95
96	301·5	301·9	302·2	302·5	302·8	303·1	303·4	303·7	304·1	304·4	96
97	304·7	305·0	305·3	305·6	305·9	306·3	306·6	306·9	307·2	307·5	97
98	307·8	308·1	308·5	308·8	309·1	309·4	309·7	310·0	310·3	310·7	98
99	311·0	311·3	311·6	311·9	312·2	312·5	312·9	313·2	313·5	313·8	99
100	314·1	314·4	314·7	315·1	315·4	315·7	316·0	316·3	316·6	316·9	100

Reciprocals of Numbers.*

Any sum multiplied by the reciprocal of a number is equal to the same sum divided by the number which the reciprocal represents. Reciprocals are frequently useful for facilitating hasty calculations; the reciprocal, used as a multiplier, being substituted for its number used as a divisor.

In the Table the reciprocals are those of whole numbers and decimals mixed; but it is easy to extend their use to whole numbers alone, or decimals alone, by adding to the reciprocal in the Table a decimal point for each integer added to its number, or deducting a decimal point for each integer subtracted from its number.

Thus, reciprocal	of	20·9	=	·047847
,,	of	209·0	=	·0047847
,,	of	2090·0	=	·00047847
,,	of	0·209	=	4·7847
,,	of	·0209	=	47·847
,,	of	·00209	=	478·47

* See Tables on following pages.

Reciprocals of Numbers.

No.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	No.
0	·0	10·000	5·00000	3·33333	2·5000	2·000	1·66667	1·42857	1·25000	1·11111	0
1	1·000	·909091	·833333	·769231	·714286	·666667	·625000	·588235	·555556	·526316	1
2	·50000	·476191	·454546	·434783	·416667	·40000	·384615	·370370	·357143	·344828	2
3	·333333	·322581	·312500	·303030	·294118	·285714	·277778	270270	·263158	·256410	3
4	·25000	·243902	·238095	·232558	·227273	·222222	·217391	·212766	·208333	·204082	4
5	·20000	·196078	·192308	·188679	·185185	·181818	·178571	·175439	·172414	·169492	5
6	·166667	·163934	·161290	·158730	·156250	·153846	·151515	·149254	·147059	·144928	6
7	·142857	·140845	·138889	·136986	·135135	·133333	·131579	·129870	·128205	·126582	7
8	·125000	·123457	·121951	·120482	119048	117647	·116279	·114943	·113636	·112360	8
9	·111111	·109890	·108696	·107527	·106383	·105263	·104167	·103093	·102041	·101010	9
10	·10000	·099010	·098039	·097087	·096154	·095238	·094340	·093458	·092593	·091743	10
11	·090909	·090090	·089286	·088496	·087719	·086957	·086207	·085470	·084746	·084034	11
12	·083333	·082645	081967	·081301	·080645	·080000	·079366	·078740	·078125	·077519	12
13	·076923	·076336	·075758	·075188	074627	·074074	·073529	·072993	·072464	·071942	13
14	·071429	·070922	·070423	·069930	·069444	068965	·068493	·068027	·067568	·067114	14
15	·066667	·066225	·065789	·065359	·064935	064516	·064103	·063694	·063291	·062893	15
16	·062500	·062112	·061728	·061350	·060976	·060606	·060241	·059880	·059524	·059172	16
17	·058824	·058480	·058140	·057803	·057471	·057143	·056818	·056497	·056180	·055866	17
18	·055556	·055249	054945	·054645	·054348	·054054	·053763	·053476	053191	·052910	18
19	·052632	·052356	·052083	051813	·051546	·051282	·051020	·050761	·050505	·050251	19

RECIPROCALS OF NUMBERS—*Continued.*

No.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	No.
20	·050000	·049751	·049505	·049261	·049020	·048780	·048544	·048309	·048077	·047847	20
21	·047619	·047393	·047170	·046948	·046729	·046512	·046296	·046083	·045872	·045662	21
22	·045455	·045249	·045045	·044843	·044643	·044444	·044248	·044053	·043860	043668	22
23	·043478	·043290	·043103	·042918	·042735	·042553	·042373	·042194	·042017	041841	23
24	·041667	·041494	·041322	·041152	·040984	·040816	·040650	·040486	·040323	·040161	24
25	·040000	·039841	·039683	·039526	·039370	·039216	·039063	·038911	·038760	·038610	25
26	·038462	·038314	·038168	·038023	·037879	·037736	·037594	·037453	·037313	·037175	26
27	·037037	·036900	·036765	·036630	·036496	·036364	·036232	·036101	·035971	·035842	27
28	·035714	·035587	·035461	·035336	·035211	·035088	·034965	·034843	·034722	·034602	28
29	·034483	·034364	·034247	·034130	·034014	·033898	·033784	·033670	·033557	·033445	29
30	·033333	·033223	·033113	·033003	·032895	·032787	·032680	·032573	·032468	·032362	30
31	·032258	·032154	·032051	·031949	·031847	·031746	·031646	·031546	·031447	·031348	31
32	·031250	·031153	·031056	·030960	·030864	·030769	·030675	·030581	·030488	·030395	32
33	·030303	·030211	·030120	·030030	·029940	·029851	·029762	·029674	·029586	·029499	33
34	·029412	·029326	·029240	·029154	·029070	·028986	·028902	·028818	·028736	·028653	34
35	·028571	·028490	·028409	·028329	·028249	·028169	·028090	·028011	·027933	·027855	35
36	·027778	·027701	·027624	·027548	·027473	027397	·027322	·027248	·027174	·027100	36
37	·027027	·026954	·026882	·026810	·026738	·026667	·026596	·026525	·026455	·026385	37
38	·026316	·026247	·026178	·026110	·026042	·025974	·025907	·025840	·025773	·025707	38
39	·025641	·025575	·025510	·025445	·025381	·025316	·025253	·025189	·025126	·025063	39
40	·025000	·024938	·024876	·024814	·024752	024691	·024631	·024570	·024510	·024450	40

RECIPROCALS OF NUMBERS—*Continued.*

No.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	No.
41	·024390	·024331	·024272	·024213	·024154	·024096	·024038	·023981	·023923	·023866	41
42	·023810	·023753	·023697	·023641	·023585	·023529	·023474	·023419	·023364	·023310	42
43	·023256	·023202	·023148	·023095	·023041	·022989	·022936	022883	·022831	·022779	43
44	·022727	·022676	·022624	·022573	·022523	·022472	·022422	·022371	·022321	·022272	44
45	·022222	·022173	·022124	·022075	·022026	·021978	·021930	·021882	·021834	·021786	45
46	·021739	·021692	·021645	·021598	·021552	·021505	·021459	·021413	·021368	·021322	46
47	·021277	·021231	·021186	·021142	·021097	·021053	·021008	·020964	·020921	·020877	47
48	·020833	·020790	·020747	·020704	·020661	·020619	·020576	·020534	·020492	·020450	48
49	·020408	·020367	·020325	·020284	·020243	·020202	·020161	·020121	·020080	·020040	49
50	·020000	·019961	·019920	·019881	·019841	·019802	·019763	·019724	·019685	·019646	50
51	·019608	·019569	·019531	·019493	·019455	·019417	·019380	·019342	·019305	·019268	51
52	·019231	·019194	·019157	·019120	·019084	·019048	·019011	·018975	·018939	·018904	52
53	·018868	·018832	·018797	·018762	·018727	·018692	·018657	·018622	·018587	·018553	53
54	.018519	·018484	·018450	·018416	·018382	·018349	·018315	·018282	·018248	·018215	54
55	·018182	·018149	·018116	·018083	·018051	·018018	·017896	·017953	·017921	·017889	55
56	·017857	·017825	·017794	·017762	·017731	·017699	·017668	·017637	·017606	·017575	56
57	·017544	·017513	·017483	·017452	·017422	·017391	·017361	·017331	·017301	·017271	57
58	·017241	·017212	·017182	·017153	·017123	·017094	·017065	·017036	·017007	·016978	58
59	·016949	016920	·016892	·016863	·016835	·016807	·016779	·016750	·016722	·016694	59
60	·016667	·016639	·016611	·016584	·016556	·016529	·016502	·016474	·016447	·016420	60

RECIPROCALS OF NUMBERS—*Continued.*

No.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	No.
61	·016393	·016367	·016340	·016313	·016287	·016260	·016234	·016207	·016181	·016155	61
62	·016129	·016103	·016077	·016051	·016026	·016000	·015974	·015949	·015924	·015898	62
63	·015873	·015848	·015823	.015798	·015773	·015748	·015723	·015699	·015674	·015649	63
64	·015625	·015601	·015576	·015552	·015528	·015504	·015480	·015456	·015432	·015408	64
65	·015385	·015361	·015337	·015314	·015291	·015267	·015244	·015221	·015198	·015175	65
66	·015152	·015129	·015106	·015083	·015060	·015038	·015015	·014993	·014970	·014948	66
67	·014925	·014903	·014881	·014859	·014837	·014815	·014793	·014771	·014749	014728	67
68	·014706	·014684	·014663	·014641	·014620	014599	·014577	·014556	014535	014514	68
69	·014493	·014472	·014451	·014430	·014409	·014388	·014368	·014347	·014327	014306	69
70	·014286	·014265	·014245	·014225	·014205	·014184	·014164	·014144	014124	·014104	70
71	.014085	014065	·014045	·014025	·014006	013986	013966	·013947	·013928	013908	71
72	·013889	013870	·013850	·013831	·013812	·013793	·013774	013755	013736	·013717	72
73	·013699	·013680	013661	·013643	·013624	·013605	·013587	·013569	·013550	·103532	73
74	·013514	·013495	·013477	·013459	·013441	·013423	·013405	·013387	·013369	·013351	74
75	·013333	·013316	·013298	·013280	013263	·013245	·013228	·013210	013193	·013175	75
76	013158	013141	013123	·013106	·013089	·013072	·013055	·013038	·013021	·013004	76
77	·012987	·012970	·012953	·012937	·012920	·012903	012887	·012870	·012853	·012837	77
78	·012821	012804	·012788	·012771	·012755	·012739	·012723	·012706	·012690	·012674	78
79	·012658	·012642	·012626	·012610	·012594	·012579	·012563	·012547	·012531	012516	79
80	·012500	·012484	·012469	·012453	·012438	·012422	·012407	·012392	·012376	012361	80

RECIPROCALS OF NUMBERS—*Continued.*

No.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	No.
81	·012346	·012330	·012315	·012300	·012285	·012270	·012255	·012240	·012225	·012210	81
82	·012195	·012180	·012165	·012151	·012136	·012121	·012107	·012092	·012077	·012063	82
83	·012048	·012034	·012019	·012005	·011990	·011976	·011962	·011947	·011933	·011919	83
84	·011905	·011891	·011876	·011862	·011848	·011834	·011820	·011806	·011792	·011779	84
85	·011765	·011751	·011737	·011723	·011710	·011696	·011682	·011669	·011655	·011641	85
86	·011628	·011614	·011601	·011587	·011574	·011561	·011547	·011534	·011521	·011507	86
87	·011494	·011481	·011468	·011455	·011442	·011429	·011416	·011403	·011390	·011377	87
88	·011364	·011351	·011338	·011325	·011312	·011299	·011287	·011274	·011261	·011249	88
89	·011236	·011223	·011211	·011198	·011186	·011173	·011161	·011148	·011136	·011123	89
90	·011111	·011099	·011086	·011074	·011062	·011050	·011038	·011025	·011013	·011001	90
91	·010989	·010977	·010965	·010953	·010941	·010929	·010917	·010905	·010893	·010881	91
92	·010870	·010858	·010846	·010834	·010823	·010811	·010799	·010787	·010776	·010764	92
93	·010753	·010741	·010730	·010718	·010707	·010695	·010684	·010672	·010661	·010650	93
94	·010638	·010627	·010616	·010604	·010593	·010582	·010571	·010560	·010549	·010537	94
95	·010526	·010515	·010504	·010493	·010482	·010471	·010460	·010449	·010438	·010428	95
96	·010417	·010406	·010395	·010384	·010373	·010363	·010352	·010341	·010331	·010320	96
97	·010309	·010299	·010288	·010277	·010267	·010256	·010246	·010235	·010225	·010215	97
98	·010204	·010194	·010183	·010173	·010163	·010152	·010142	·010132	·010121	·010111	98
99	·010101	·010091	010081	·010070	·010060	·010050	010040	·010030	·010020	·010010	99
100	·010000	·009990	·009980	·009970	·009960	·009950	·009940	·009930	·009921	·009911	100

Paper.

1 ream = 20 quires = 480 sheets.
1 quire = 24 sheets.

Drawing Paper.

Cap,	13 × 16 inches
Demy,	20 „ 15 „
Medium,	22 „ 17 „
Royal,	24 „ 19 „
Super Royal,	27 „ 19 „
Imperial,	30 „ 21 „
Elephant,	28 „ 22 „
Columbier,	34 „ 23 „
Atlas,	33 „ 26 „
Theorem,	34 „ 28 „
Double Elephant,	40 „ 26 „
Antiquarian,	52 „ 31 „
Emperor,	40 „ 60 „
Uncle Sam,	48 „ 120 „

Continuous Colossal Drawing Paper, No. A and No. B, 56 inches wide, and of any required length. No. A of this paper is excellent for mechanical drawings.

Tracing Paper.

Double Crown,	30 by 20 ins.	Glazed or Crystal, Yellow or Blue Wove.
Double Double Crown,	40 „ 30 „	
Double Double Double Crown,	60 „ 40 „	

Finest French Vegetable Tracing Paper.

Grand Rasin (or Royal), 24 in. by 18. Grand Aigle, 40 in. by 27.

Mounted Tracing Paper.

This paper is mounted on cloth, and is still transparent; it will take ink and water-colours. It is 38 inches wide, and of any required length.

Vellum Writing Cloth.

Adapted for every description of tracing; it is transparent, durable, and strong. It is 18 to 38 inches wide, and of any required length.

Birmingham Gauge for Wire, Sheet Iron, and Steel.

No. B. W. G.	Thickness in inches.	Weight per Square Foot in Pounds.				Approximate Thickness in inches.
		Sheet and Boiler Iron.	Sheet Cast Steel.	Sheet Copper.	Sheet Lead.	
0000	·454	18·267	18·259	20·566	26·75	7 : 16
000	·425	17·053	17·280	19·252	25·06	27 : 64
00	·380	15·247	15·451	17·214	22·42	3 : 8
0	·340	13·7	14·0	15·6	20·06	11 : 32
1	·300	12·1	12·4	13·8	17·72	5 : 16
2	·284	11·4	11·7	13·0	16·75	9 : 32
3	·259	10·4	10·6	11·9	15·26	1 : 4
4	·238	9·60	9·80	11·0	14·02	7 : 32
5	·220	8·85	9·02	10·1	12·98	7 : 32
6	.203	8·17	8·33	9·32	11·98	7 : 32
7	·180	7·24	7·38	8·25	10·63	3 : 16
8	·165	6·65	6·78	7·59	9·73	3 : 16
9	·148	5·96	6·08	6·80	8·72	5 : 32
10	·134	5·40	5·51	6·16	7·90	5 : 32
11	·120	4·83	4·93	5·51	7·08	1 : 8
12	·109	4·40	4·50	5·02	6·42	1 : 8
13	·095	3·83	3·91	4·37	5·60	3 : 32
14	·083	3·34	3·41	3·81	4·90	3 : 32
15	·072	2·90	2·96	3·31	4·25	1 : 16
16	·065	2·62	2·67	3·00	3·83	1 : 16
17	·058	2·34	2·39	2·67	3·42	1 : 16
18	·049	1·97	2·01	2·25	2·90	1 : 16
19	·042	1·69	1·72	1·93	2·48	3 : 64
20	·035	1·41	1·42	1·61	2·04	3 : 64
21	·032	1·29	1·31	1·47	1·89	3 : 64
22	·028	1·13	1·15	1·29	1·65	1 : 32

Birmingham Gauge for Wire, Sheet Iron, and Steel—*Continued.*

No. B. W. G.	Thickness in Inches.	Weight per Square Foot in Pounds.				Approximate Thickness in Inches.
		Sheet and Boiler Iron.	Sheet Cast Steel.	Sheet Copper.	Sheet Lead.	
23	·025	1·00	1 02	1·14	1·47	1 : 32
24	·022	0·885	0 903	1·01	1·30	1 : 32
25	·020	0·805	0 820	0·918	1·18	1 : 32
26	·018	0·724	0·738	0·826	1·06	1 : 64
27	·016	0·644	0·657	0·735	0·945	1 : 64
28	·014	0·563	0·574	0 642	0·826	
29	·013	0·523	0·533	0·597	0 767	
30	·012	0·483	0 493	0·551	0 708	
31	·010	0 402	0·410	0·480	0·600	
32	·009	0·362	0·370	0·420	0·532	
33	·008	0·322	0 328	0·370	0·472	
34	·007	0·282	0·288	0·323	0·413	
35	·005	0 230	0·235	0 262	0·309	
36	·004	0·170	0·173	0·194	0 236	

Birmingham Gauge for Silver and Gold.

No.	Thick. Inch.	No.	Thick. Inch	No.	Thick. Inch.	No.	Thick. Inch.	No.	Thick. Inch.	No.	Thick. Inch.
1	·004		·015	13	·036	19	·064	25	·095	31	·133
2	·005	8	·016	14	·041	20	·067	26	·103	32	·143
3	·008	9	·019	15	·047	21	·072	27	·113	33	·145
4	.010	10	·024	16	·051	22	·074	28	·120	34	·148
5	.013	11	·029	17	·057	23	·077	29	·120	35	·158
6	·013	12	·034	18	·061	24	·082	30	·126	36	·167

Comparative Table of Different Wire Gauges in Use.

British Standard Gauge.		Birmingham Gauge.		American Gauge.		French Decimal Gauge.	
No. S. W. G.	Diameter in inches.	No. B. W. G.	Diameter in inches.	No. A. W. G.	Diameter in inches.	No. F. W. G.	Diameter in millimetres.
7/0	·500	...	...	...	...	...	...
6/0	·464	0000	·454	0000	·4600	...	...
5/0	·432	000	·425	...	...	...	...
4/0	·400	...	...	000	·4096	...	...
3/0	·372	00	·380	00	·3648	...	...
2/0	·348	0	·340	...	..	...	...
0	·324	...	...	0	·3249	...	...
1	·300	1	·300	...	...	...	...
2	·276	2	·284	1	·2893		...
3	·252	3	·259	2	·2576	...	...
4	·232	4	·238	3	·2294	...	...
5	·212	5	·220	...	...	...	...
6	·192	6	·203	4	·2043	...	5·0
7	·176	7	·180	5	·1819	20	4·4
8	·160	8	·165	6	·1620	...	...
9	·144	9	·148	7	·1443	19	3·9
10	·128	10	·134	8	·1285	18	3·4
11	·116	11	·120	9	·1144	17	3 0
12	·104	12	·109	10	·1019	16	2·7
13	·092	13	·095	11	·0907	15	2·4
14	·080	14	·083	12	·0808	14	2·2

Comparative Table of Different Wire Gauges in Use.—*Continued.*

British Standard Gauge.		Birmingham Gauge.		American Gauge.		French Decimal Gauge.	
No. S. W. G.	Diameter in inches.	No. B. W. G.	Diameter in inches.	No. A. W. G.	Diameter in inches.	No. F. W. G.	Diameter in millimetres.
...	...	...	...	...	...	13	2·0
15	·072	15	·072	13	·0720	12	1·8
16	·064	16	·065	14	·0641	11	1·6
17	·056	17	·058	15	·0571	10	1·5
...	...	...	...	...	...	9	1·4
...	...	...	...	...	...	8	1·3
18	·048	18	·049	16	·0508	7	1·2
...	...	19	·042	17	·0453	6	1·1
19	·040	...	...	18	·0403	5	1·0
20	·036	20	·035	19	·0359	4	0·9
21	·032	21	·032	20	·0320	3	0·8
22	·028	22	·028	21	·0285	2	0·7
23	·024	23	.025	22	·0253	1	0·6
24	·022	24	·022	23	·0226	...	...
25	·020	25	·020	24	·0201	p	0·5
26	·018	26	·018	25	·0179	...	..
27	·0164	27	·016	26	·0159	...	...
28	·0148	28	014	27	·0142	...	..
29	·0136	29	·013	...	...	...	..
30	·0124	30	·012	28	·0126	...	...

Comparative Table of Different Wire Gauges in Use.—*Continued.*

British Standard Gauge.		Birmingham Gauge.		American Gauge.		French Decimal Gauge.	
No. S. W. G.	Diameter in inches.	No. B. W.G.	Diameter in inches.	No. A. W. G.	Diameter in inches.	No. F. W. G.	Diameter in millimetres.
31	·0116	...	...	29	·0113	...	...
32	·0108	...	...	...	...	...	...
33	·0100	31	·010	30	·0100	...	...
34	·0092	32	·009	31	·0089	...	...
35	·0084	33	·008	32	·0080	...	...
36	·0076	34	·007	33	·0071	...	...
37	·0068	...	...	...	...	..	...
38	·0060	...	...	34	·0063	...	...
39	·0052	...	...	35	·0056	...	...
40	·0048	35	·005	36	·0050	...	...
41	·0044	...	...	37	·0045	...	...
42	·0040	36	·004	38	·0040	...	...
43	·0036	...	...	39	.0035	...	...
44	·0032	...	...	...	...	...	...
45	·0028	...	...	40	·0031	..	...
46	·0024	...	...	...	...	..	...
47	·0020	...	...	...	...	...	...
48	·0016	...	...	...	...	..	...
49	·0012	...	...	...	...	...	...
50	·0010	...	...	...	...	..	...

TESTING.

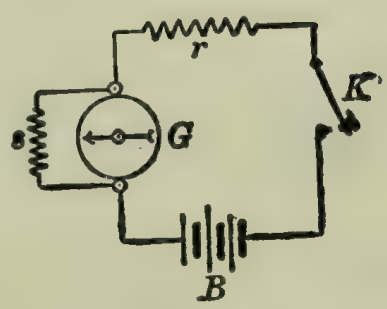
Ohm's Law.—

Let E = the electro-motive force of battery in volts,
R = the total resistance in circuit in ohms,
C = the current in amperes.

Then, $$C = \frac{E}{R}, \text{ amperes.}$$

$$\therefore\ E = C \times R, \text{ volts.}$$

$$\therefore\ R = \frac{E}{C}, \text{ ohms.}$$



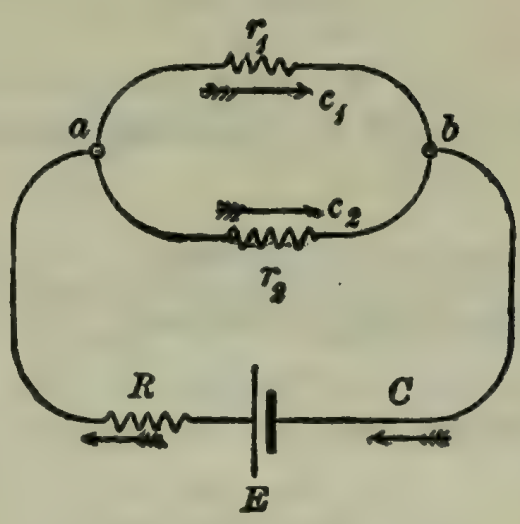
If, as in the fig., $R = B + \frac{G\,s}{G + s} + r$, ohms

Then, $$C = \frac{E}{B + \frac{G\,s}{G + s} + r}, \text{ amperes.}$$

$$E = C\left(B + \frac{G\,s}{G + s} + r\right), \text{ volts.}$$

and $$\frac{E}{C} = B + \frac{G\,s}{G + s} + r, \text{ ohms.}$$

Currents and Derived Circuits.—A current splits among derived circuits in proportion to their conductivities—*i.e.*, the inverse ratio of their resistances.



Let R, r_1, r_2 in the fig. be the resistances of three circuits connected together at the points *a*, *b*; and C, c_1, c_2, the currents produced in them respectively by the battery of electromotive force, E.

$$\text{Then, } C = E\frac{r_1 + r_2}{R\,r_1 + R\,r_2 + r_1\,r_2}$$

$$c_1 = E\frac{r_2}{R\,r_1 + R\,r_2 + r_1\,r_2}$$

$$c_2 = E\frac{r_1}{R\,r_1 + R\,r_2 + r_1\,r_2}.$$

Resistance of Derived Circuits.—The *joint conductivity* of a number of derived circuits connected in "multiple arc" is the sum of the conductivities of the several loops.* The *joint resistance* of any number of wires connected in parallel circuit is equal to the reciprocal of the sum of the reciprocals of their resistances. Thus :—

The joint conductivity of several wires, r_1, r_2, r_3, : - - in multiple arc is,

$$\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}+ - - - - -$$

The joint resistance of several wires in multiple arc is,

$$\frac{1}{\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}+ - - -}$$

The joint resistance of two wires, r_1, r_2, in multiple arc (fig., p. 66) is,

$$\frac{1}{\frac{1}{r_1}+\frac{1}{r_2}}=\frac{r_1\,r_2}{r_1+r_2}=\frac{\text{product of their resistances}}{\text{sum of their resistances}}=\mathrm{R}'$$

The resistance required to give a joint resistance R′, when joined with r_2, is,

$$r_1=\frac{\mathrm{R}'\,.\,r_2}{r_2-\mathrm{R}'}\,.$$

The total resistance of the circuit with derivations r_1, r_2 (fig., p. 66), is,

$$\mathrm{R}+\mathrm{R}'=\mathrm{R}+\frac{r_1\,r_2}{r_1+r_2}.$$

* Loop circuits: "in loop," &c., might be used instead of existing terms.

Shunts.—

The joint resistance of a galvanometer and shunt

$$= \frac{G \times s}{G + s}.$$

where G = resistance of galvanometer.
s = ,, ,, shunt.

The Multiplying Power of a shunt is the ratio of the total current, C, flowing in the circuit, to that part of it, C_1, which goes through the galvanometer coil.
Thus :—

$$\frac{C}{C_1} = \frac{G + s}{s} = \frac{G}{s} + 1.$$

The shunt required to give a certain multiplying power, n,

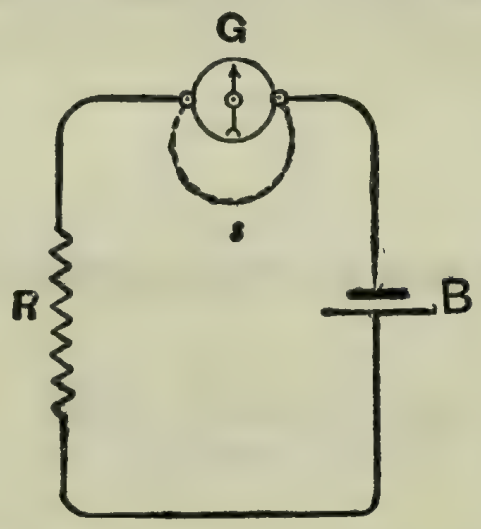
$$= \frac{G}{n - 1}.$$

n is usually 10, 100, or 1000.

The joint resistance of G and s is then $= \frac{G}{n}$, and *the compensating resistance* to be added to the circuit to make up G resistance, is

$$G - \frac{G}{n} = G\,\frac{n - 1}{n}.$$

Figure of merit of a galvanometer.—The degree of sensitiveness or figure of merit of a galvanometer is determined by the resistance, R_f, which, in circuit with one Daniell's element gives a deflection of 1° of arc.



Let d = deflection with resistance, R, in circuit
G = resistance of galvanometer
s = ,, ,, shunt
B = ,, ,, the cell.

Then if d is in degrees of arc,

$$R_f = d\,\frac{G + s}{s}\left(\frac{Gs}{G + s} + R + B\right).$$

With a sensitive Thomson mirror galvanometer, d may be taken as the deflections on the scale, therefore mirror galvanometers may be compared with each other by the resistance necessary to produce, with a Daniell's element, a deflection of one division on the scale.

Figure of merit of a galvanometer—*continued.*

With any battery joined in circuit with the galvanometer, and a known resistance, the sensitiveness is found by calculating the current required to give 1° deflection. For example, let a tangent galvanometer give a deflection of 50° with a 10-cell Daniell battery having an E.M.F., E, of (say) 10 volts through a total circuit resistance, R, of 1000 ohms.

$$\text{Then, } \frac{E}{R} = C, \text{ } e.g., \frac{10}{1000} = \cdot 01 \text{ amperes,}$$

and the current which would produce a deflection of 1° is

$$\cdot 01 \times \frac{\tan.\ 1^\circ}{\tan.\ 50^\circ} = \cdot 01 \times \frac{\cdot 0175}{1 \cdot 1918} = \cdot 000146 \text{ amperes.}$$

In the case of a Thomson galvanometer, divide the current by the deflection obtained, since the deflections are directly proportional to the currents producing them.

In the case of a galvanometer whose larger deflections are not proportionate to any ordinary function of the degrees of arc, it is best to use a low E. M. F. and high resistance to get a few degrees of deflection, for these will be proportionate to the currents.

The value of a Thomson galvanometer deflection can be compared with that of a tangent galvanometer by connecting both instruments in one circuit with a battery. Galvanometers are also compared by connecting them all in one circuit with a standard instrument and battery.

Deflection of one cell through a megohm.—Shunt the galvanometer G, with s, and connect it in circuit with R ohms, and one cell of resistance, B (see fig., p. 69).

Let d = observed deflection,
D = deflection through one megohm, or "constant,"

$$D = d\frac{G+s}{s} \cdot \left(\frac{Gs}{G+s} + R + B\right)10^{-6} \text{ divisions.}$$

It is usual to make the resistance of the whole circuit,

$$\frac{Gs}{G+s} + R + B = 10{,}000 \text{ ohms.}$$

In this case the "constant"

$$D = d\frac{G+s}{s} \cdot \frac{1}{100} \cdot \text{ divisions.}$$

Further, if the shunt s has a multiplying power,

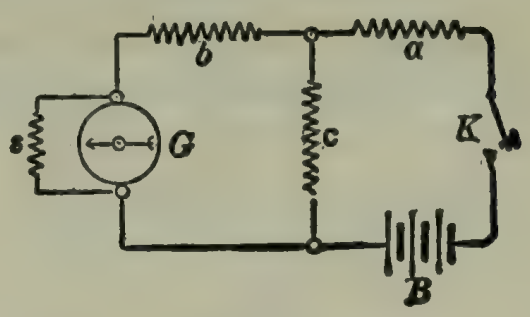
$$\frac{G+s}{s} = 100,$$

we have,

$$D = d.$$

Resistance, giving unit deflection with a given battery. —

Indirect Method (Hockin): —



In the figure,

G represents galvanometer.

s ,, shunt $= \frac{G}{999}$.

a, b, ,, resistance coils to be adjusted.

c ,, ,, coil = 1000 ohms.

B ,, battery.

K ,, key.

R ,, required resistance in megohms to produce unit deflection.

1. Obtain deflection, d, with above connections.
2. Alter a to a_1, b to b_1, and then obtain same deflection, d, as before, when R =

$$\cdot 001\, d \left\{ (a_1 - a) \frac{(b + c + \cdot 001\,G)(b_1 + c + \cdot 001\,G)}{(b - b_1)\,c} - c \right\}$$

Direct method.—The connections are the same as the foregoing method, *but leaving out resistance, a,* find resistance of battery, B. Let b and c be the variable resistances, and note resistance of G and s.

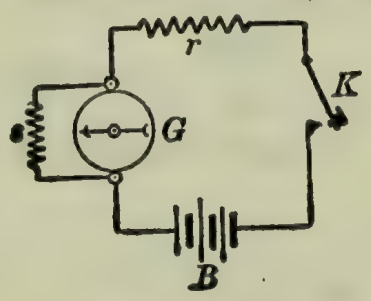
Taking the test :—

1. Adjust b (whilst circuit, c, is broken) until a convenient deflection is obtained, then c is joined up as shown in the last figure, and b is adjusted to b_1 until the same deflection is obtained as before. With these data we obtain the battery resistance,

$$B = c \frac{b - b_1}{\frac{Gs}{G+s} + b_1}$$

The resistance of B may be obtained by any of the other methods (see Index).

2. A direct deflection, d, is obtained with a resistance, r, in circuit, as in fig. Then,



$$R = d \frac{G+s}{s}\left(r + B + \frac{Gs}{G+s}\right)10^{-6} \text{ megohms.}$$

It is evident from the above that if we so adjust r that the total resistance in circuit,

$$r + B + \frac{Gs}{G+s} = 10{,}000 \text{ ohms,}$$

$$\text{and make } s = \frac{G}{99} \text{ or } \frac{G+s}{s} = 100.$$

$$R = d\frac{G+s}{s}\left(r + B + \frac{Gs}{G+s}\right) = d \times 100 \times 10{,}000 \quad \cdot\cdot$$

$$\therefore\ R = d \text{ megohms.}$$

By which simple method R is found at once from the deflection obtained.

CURRENTS.*

By Sine Galvanometer, $C = \sin\theta \times$ constant,

where C = the strength of current,

θ = angle through which coil is turned until the zero point coincides with the needle.

By Tangent Galvanometer,

$$C = \tan.\,\theta \times H \times \frac{r}{2\pi n}$$

where C = current in C.G.S. units.

θ = angle of deflection from zero.

H = horizontal intensity of earth's mag.

$\frac{r}{2\pi n}$ = constant of instrument.

r = mean radius of coils in centimetres.

n = number of turns of wire in coil.

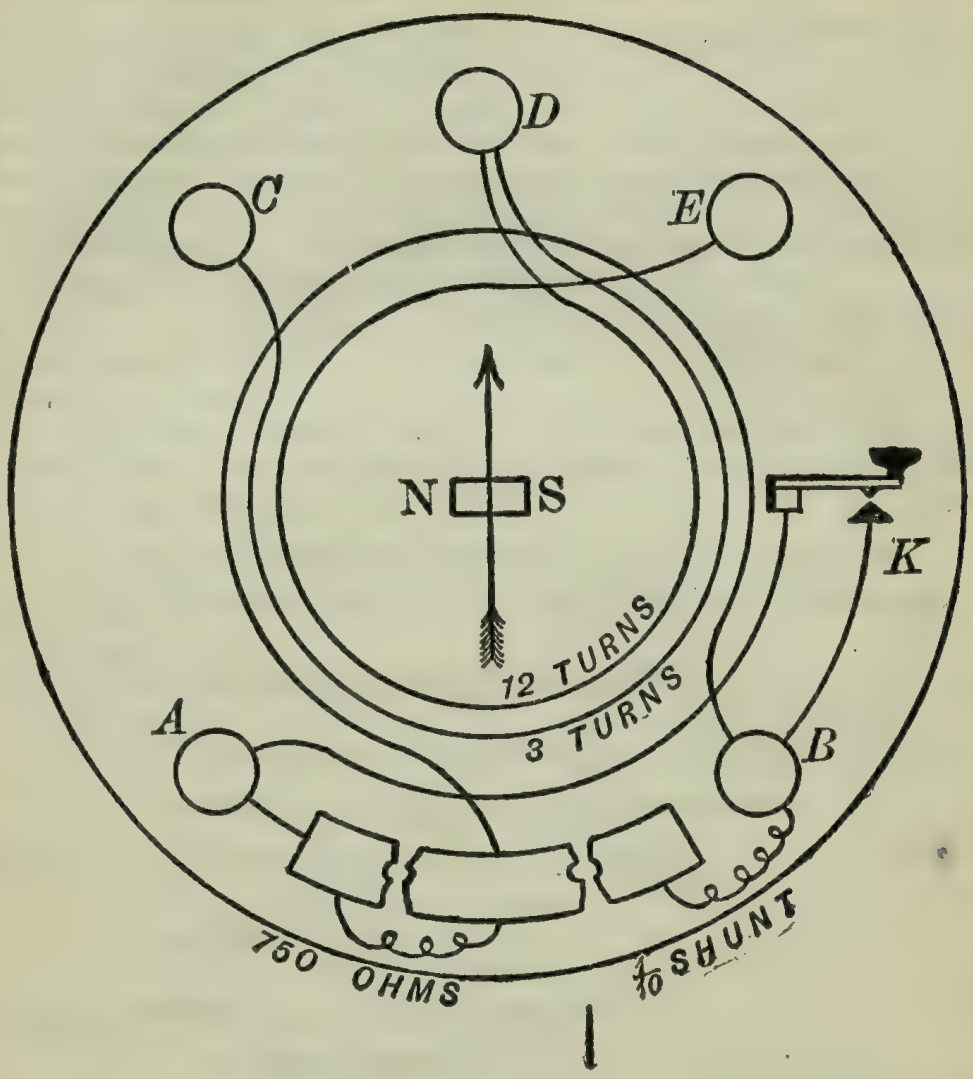
Note.—H varies from ·15 to ·18 C.G.S. units in Great Britain, but it should always be determined for the place of observation to avoid error due to local magnetism. (See Index for Table).

The instrument is most sensitive to change of current when $\theta = 45°$. When two deflections are taken they should be as near as possible at equal distances from 45°.

In Helmholtz's tangent galvanometer there are two equal coils with their planes vertical and parallel, placed so that the distance of each coil from the centre of the magnet is equal to *half* the radius of either coil. When there are several layers of wire in either coil, the distance between the mean planes of the coils is equal to the mean radius of each. The ratio of the depth to the thickness of the grooves containing the coils should be "as $\sqrt{36}$ to $\sqrt{31}$," or about 6 to 5·5.

$$\text{Helmholtz's constant} = \frac{5r\sqrt{5}}{16\pi n}.$$

* For current electro-deposition, see foot of p. 344.



G.P.O. Instructions for Tangent Galvanometer Connections.

Between C and D are three turns of 50 mils copper wire.

Between D and E are twelve turns of the same, wound the reverse way.

Between B and the middle block of the switch is a galvanometer coil having a resistance of 320 ohms.

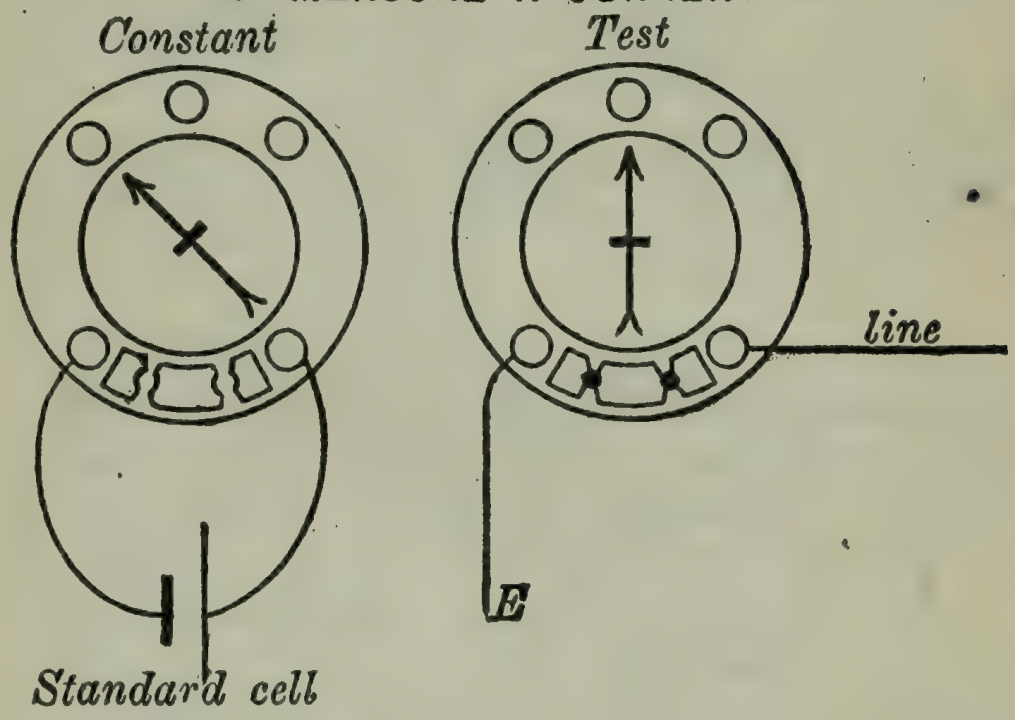
When the left-hand plug is inserted, and the right-hand plug is out, the resistance between the terminals, A and B, is 320 ohms. When the right-hand plug is inserted, the current passing through the galvanometer is only $\frac{1}{10}$ of that flowing in the circuit.

The key is to enable the needle to be readily brought to rest.

The directing magnet should be kept in line with the zero position of the galvanometer magnet. The sensitiveness of the needle is greater when the similar poles of the two magnets point in the same direction and less when they point in opposite directions. Any further adjustment of sensitiveness required can be obtained by raising or lowering the directing magnet.

In making tests care must be taken that the pointer stands at zero when no current is flowing.

TO MEASURE A CURRENT



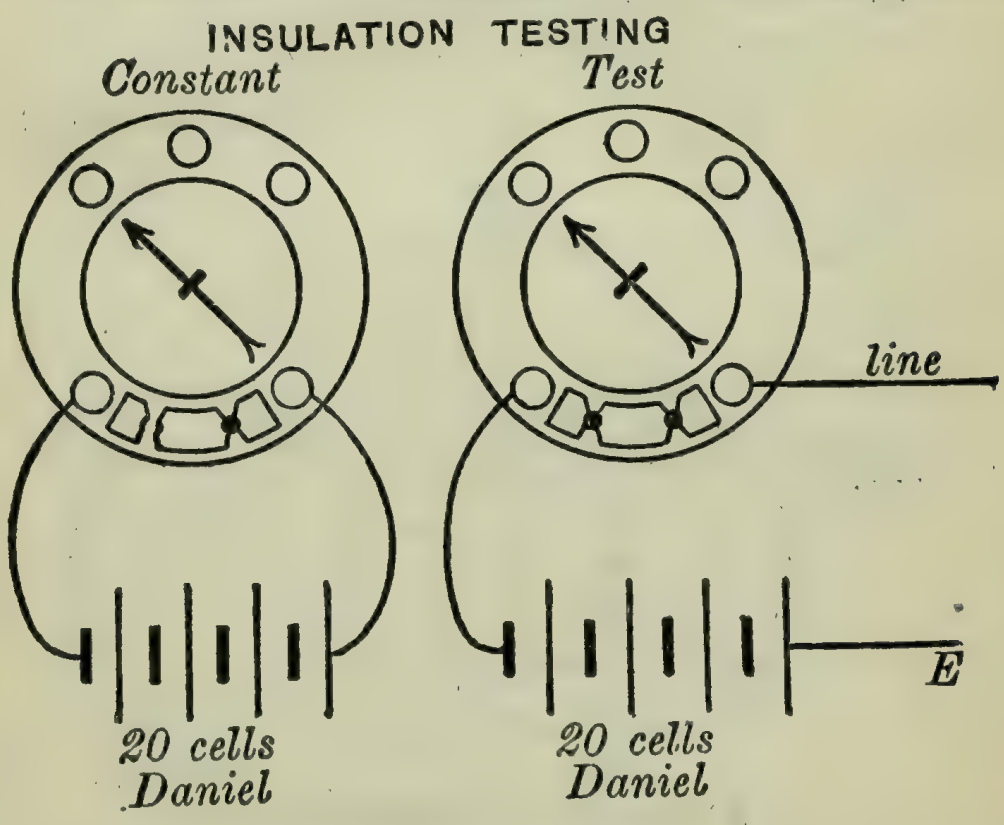
The "constant" is a deflection of 25° produced by one milliampere of current. To obtain it both plugs of the galvanometer are removed and the directing magnet adjusted until the current from a standard cell gives a deflection of 25°.

The test is then made by noting the deflection produced by the current which is to be measured. If the deflection is very small the right-hand plug may be removed; but in that case the corresponding result obtained from a milliampere table must be divided by ten.

Ordinary Insulation Testing.

20 Daniell cells are used both for taking the constant and making the test. ("Ordinary" batteries may not be used for this purpose.)

(1) To take the constant put in only the right-hand plug.



(The "constant" is any deflection given by the 20 cells under the conditions shown in the diagram.)

(2) To test the insulation put in both plugs.

The two deflections give the relation between the insulation resistance and 1000 ohms.

The line must be disconnected at the further end.

The resistance corresponding to the deflection of the galvanometer is the total insulation resistance of the line. If the reading be very low the right-hand plug may be removed, in which case the resistance which corresponds to the deflection obtained must be multiplied by ten.

The result multiplied by the number of miles of line gives the insulation per mile.

By Obach's Movable Coil Galvanometer.

1. *General Method.*—Turn the coil until a deflection, θ, somewhere near 45 deg., is obtained, then read off the inclination ϕ of the coil.

Then, $C = \tan. \theta \times \sec. \phi \times$ constant.

2. *Method of Equality.*—Turn the coil until the deflection, θ, and the inclination, ϕ, are at one and the same angle, ψ.

Then, $C = \tan. \psi \times \sec. \psi \times$ constant.

These products of tan. × sec. can be calculated beforehand and tabulated.

3. *Method of Constant Deflection.*—Turn the coil until the needle each time points to the same degree, say for convenience, $26\frac{1}{2}°$, $45°$, or $63\frac{1}{2}°$. The tangent of this deflection enters the constant, and the formula is reduced to:

$$C = \sec. \phi \times \text{constant}.$$

The instrument here acts as a secant galvanometer, and the method has the peculiarity, that for a number of measurements the needle occupies the same position, which, in some cases, may be found of advantage.

4. *Method of Constant Inclination.*—Set the coil at a proper angle, of which the secant now enters the constant, and the instrument here simply acts as a tangent galvanometer with

$$C = \tan. \theta \times \text{constant}.$$

By Thomson's Mirror Galvanometers—(Astatic, ballistic, dead-beat, and marine).

$$C = d \times \text{constant}$$

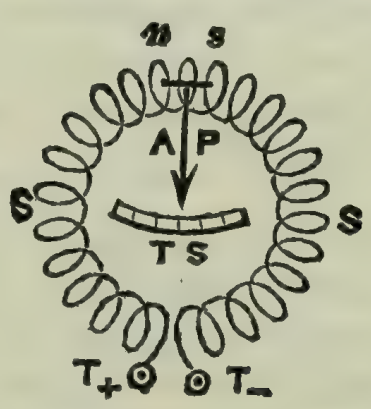
where d = deflection on the scale in divisions.

It is proportional to the tangent of twice the

angle of deflection; but this is very small, and unless extreme accuracy is required, d may be taken as proportional to the current. The first swing of the needle may be used for d.

The instrument is most sensitive when the controlling magnet is raised a little (say 1 inch) above the point at which it exactly neutralises the directive force of the earth's magnetism. The angle of maximum sensitiveness is the largest reading obtainable, the true maximum being off the scale.

By Blyth's Tangent Galvanometer.



$$C = \tan\theta \cdot H \cdot \text{constant} = \tan\theta \cdot H \cdot \frac{r}{2n},$$

Where C = current in C.G.S. units passing from, T +, to T −.

H = horizontal intensity of earth's magnetism.

r = radius of axis of solenoid (S).

n = number of convolutions in solenoid (S).

θ = angle of deflection of a small suspended magnet ($n - s$), observed by its aluminium pointer, A P, on a tangent scale, T S.

Note —It will be seen that since the solenoid is endless, it produces no magnetic force at any point outside of it; hence, should controlling magnets be used, the currents being measured have no effect in disturbing their magnetism. It may be used in the form shown in fig. for taking current strengths or E.M.F.'s.

By Electro-Dynamometer,

$$C = \sqrt{\sin\theta} \times \text{constant},$$

where θ = torsion angle of suspended coil.

The current may be constant or alternating.

By Siemens' Electro-dynamometer.—Where the movable coil is brought back to its original position,

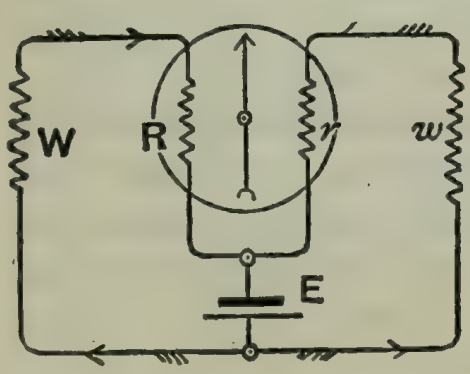
$$C = \sqrt{\theta} \times \text{constant.}$$

COMPARING CURRENTS.—Currents may be compared by an ordinary galvanoscope, if resistance is inserted or shunts applied to make both deflections equal. When a differential galvanometer is used, the deflection is proportional to the difference of the currents.

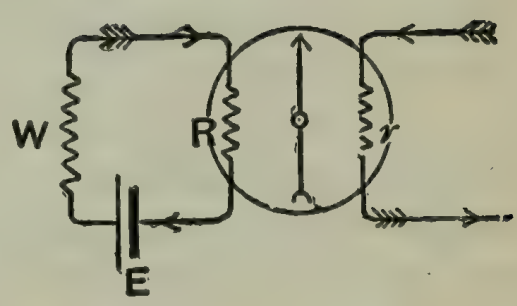
CARDEW'S GALVANOMETER, FOR MEASURING STRONG CURRENTS.—To find the constant or ratio of the power of coil, R, over the needle to that of wire, r, connect coil, R, in circuit with an adjustable resistance, W, to the poles of a battery or other difference of potential, E, and wire, r, in circuit with another resistance, w, to the same poles, as shown in figure A. Adjust W until a balance on the needle is obtained, then

$$\text{Constant} = \frac{R + W}{r + w}$$

A



B



To use the instrument, send the strong current,

such as that from a dynamo, through the low resistance wire, r, as shown in the figure, B, and balance its effect on the needle with the current of a standard Daniell cell of electro-motive force, E, by adjusting the resistance, W.

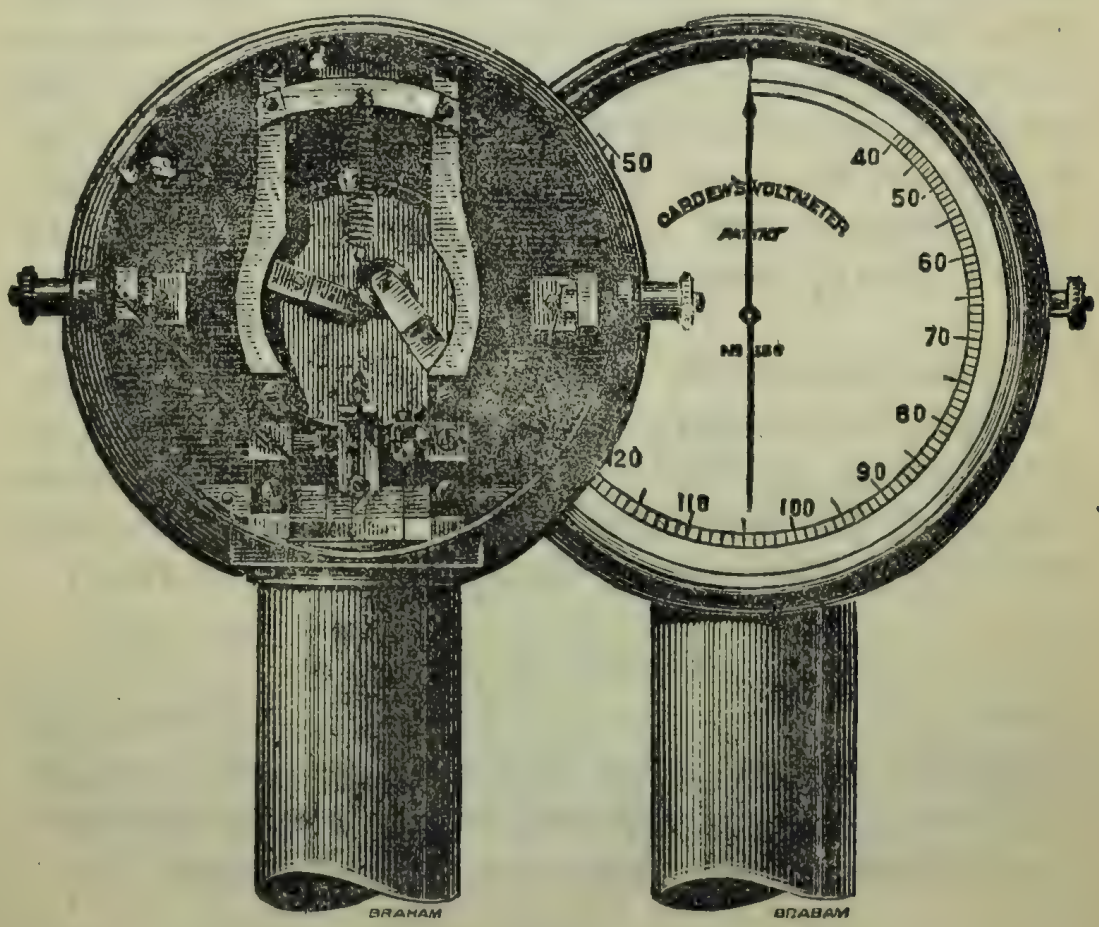
Then $$C = \frac{E}{R + W + b}$$

where C = the current in R;
and b = resistance of cell,

and $$C_1 = C \times \text{constant} = \frac{E}{R + W + b} \cdot \frac{R + W}{r + w}$$

where C_1 = current in r.

CARDEW'S VOLTMETER is based on the expansion of a fine platinum silver wire by the heating



CARDEW'S VOLTMETER.—BACK AND FRONT.

effect of the current. The wire is enclosed and supported by a tube of compound metal, whose coefficient of expansion is equal to that of the wire. This compensates for variation of external temperature, and the difference of temperature between the wire and the tube gives the reading.

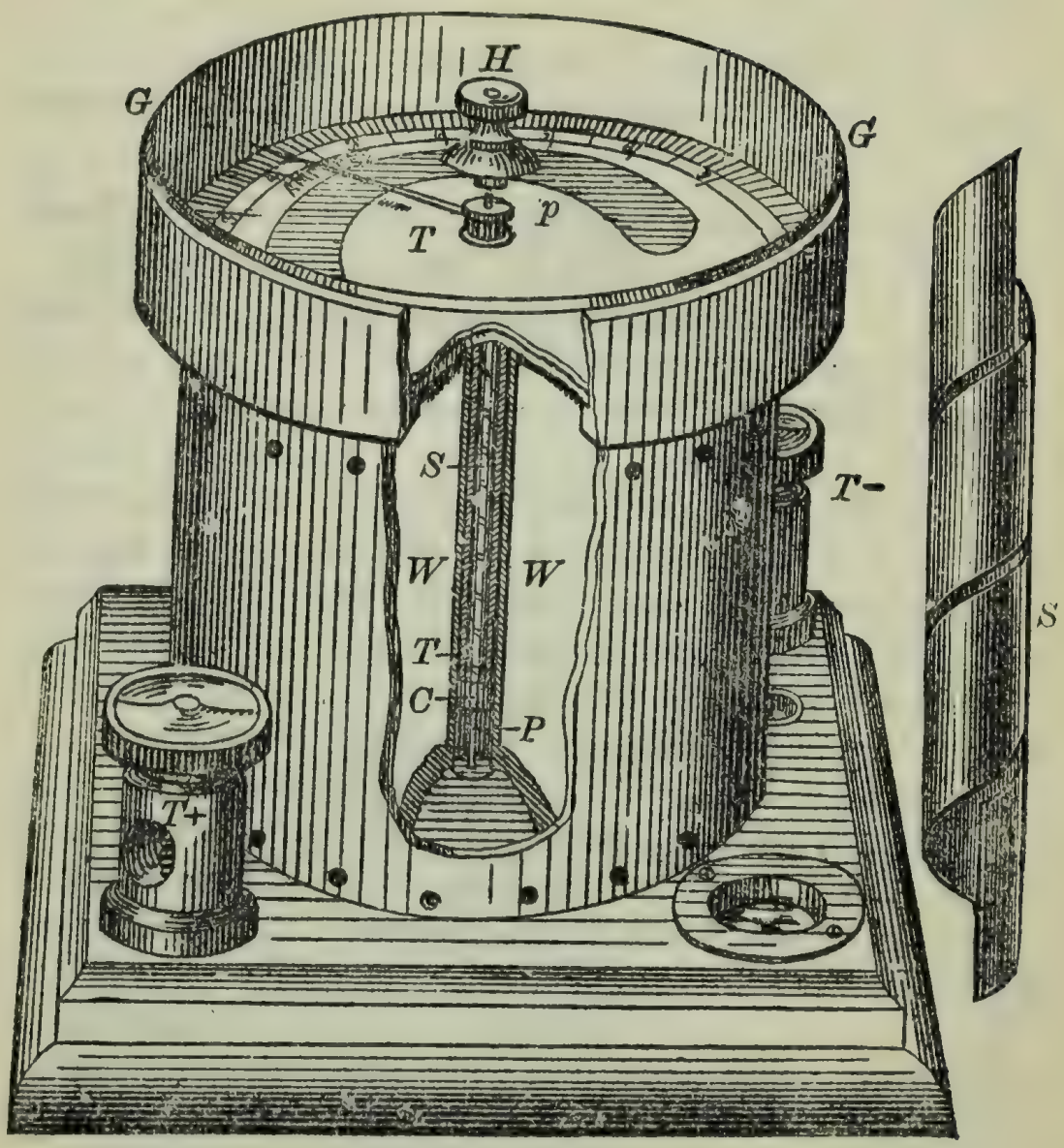
The instruments are directly marked in volts; being calibrated at a temperature of about 15° C. A small correction (about ·03 per cent. per 1° C.) is necessary for extreme accuracy—the correction is negative.

They are made for use with the tube vertical or horizontal. In the former case, the high readings are rendered somewhat uncertain by a vibration of the needle, due to connection currents in the enclosed air.

The ordinary pattern reads to 120 volts, there being 12 feet of wire taking 10 volts per foot. Longer range instruments are also made; or the range of the ordinary pattern can be increased by the use either of an additional length of the same wire supplied in a tube, or of incandescent lamps in series. Ordinary resistance bobbins should not be used. The use of incandescent lamps tends to compensate for the variation of reading due to external temperature.

The voltmeters can be kept in circuit for any time, and are quite unaffected by magnets.

Gauge of wire in ordinary pattern, resistance cold 30 ohms per foot.	·0025″
Gauge of fuse wire for ordinary pattern, resistance cold 90 ohms per foot.	·0014



AYRTON & PERRY'S MAGNIFYING SPRING AMMETER & VOLTMETER.

Index to Diagram.

T T, for thin tube of charcoal iron attached to

C, „ cap terminating in

P, „ pin made of brass guided as shown.

S, „ spring (made of phosphor bronze, see enlarged view at side). This spring is attached at lower end to, C, and at upper end to

p,	for	pin passing through a hole in
G G,	„	glass top, and there fastened to
H,	„	head of milled nut outside glass.
W W,	„	wire coils or strip forming the solenoid, whose ends are attached to
T +, T −,	„	terminals positive and negative.

Mode of Action.

When a continuous current is passed through this solenoid the thin iron tube, T T, is sucked down, thus elongating the spring, S, and turning the light aluminium pointer (attached to the tube at top, T, under the glass cover) round proportional to the current as indicated by the scale. Parallax in taking readings is avoided by the horizontal scale having a piece of looking-glass let in as shown. These commercial instruments are calibrated in the first instance by comparison with a standard one, which has been graduated by the silver or copper deposit methods (see Index for graduating volt and ammeters). If carefully handled they do not require recalibration (see *Jour. Soc. Tel. Engs.*, vol. xvi., pp. 566, 567, 1887). All that is necessary before using the instrument is to see that the pointer moves freely and that it points to, O, of the scale. In the case of the voltmeter the small white push button must be pressed down to close the voltmeter circuit when taking an observation. The small compass needle seen on the right, indicates the direction of the current. These instruments are not accurate with or intended for measuring alternate currents.

Sir William Thomson's New Standard Direct Reading Electric Balances.*

1. These instruments are founded on the mutual forces, discovered by Ampère, between movable and fixed portions of an electric circuit. The shape chosen for the mutually-influencing portions is circular, and each part is called an Ampère ring; or sometimes simply a ring, whether it consists of only one turn or of any number of turns of the conductor; or an arc when it consists of less than a whole turn. (See Figs. further on.)

2. In each of the balance instruments, except the kilo-ampere balance, each movable ring is actuated by two fixed rings—all three approximately horizontal. There are two such groups of three rings—two movable rings attached to the two ends of a horizontal balance arm pulled, one of them up and the other down, by a pair of fixed rings in its neighbourhood. The current is in opposite directions through the two movable rings to practically annul disturbance due to horizontal components of terrestrial or local magnetic forces. In the Inspectional Voltmeter each movable ring is actuated by only one fixed ring, which is fixed beneath the movable ring at one end and above it at the other. In the kilo-ampere balance the whole current passes through a single fixed ring and divides through two halves of a movable ring, which are urged one up and the other down by the resulting Ampèrian force.

3. In all the instruments the balance arm is supported by two trunnions, each hung by a flexible ligament of fine wire through which the current passes into and out of the circuit of the movable rings or ring.

4. In all the balance instruments, in which the movable ring is between two fixed rings, the mid-range position of each movable ring is in the horizontal plane nearly midway between the two fixed rings which act on it. The current goes in opposite directions through the two fixed rings, so that the movable ring is attracted by one of the fixed rings and repelled by the other. The position of the movable ring equidistant from the two fixed rings, is a position of minimum force, and the sighted position, for the sake of stability, is above it at one end of the beam

* For further instructions see *Journal Soc. Tel. Engineers and Electricians*, part 74, vol. xvii., and pamphlet of instructions (issued by Mr. James White, Optician, Cambridge Street, Glasgow, maker of all these instruments), containing Tables for facilitating the calculations, such as doubled square roots, &c.

and below it at the other, in each case being nearer to the repelling than to the attracting ring by such an amount as to give about $\frac{2}{10}$ per cent. more than the minimum force.

5. In the balance instruments to measure alternate currents (which may be also used for direct currents) of from 1 ampere to 600 amperes, the main current through each circle, whether of one turn or of more than one turn, is carried by a wire rope of which each component wire is insulated by silk covering, or otherwise, from its neighbour, in order to prevent the inductive action from altering the distribution of the current across the transverse section of the conductor.

6. The balancing is performed by means of a weight which slides on an approximately horizontal graduated arm attached to the balance; and there is a trough fixed on the right hand end of the balance into which a proper counterpoise weight is placed, according to the particular one of the sliding weights in use at any time (§ 9 below). For the fine adjustment of the zero a small metal flag is provided, as in an ordinary chemical balance. This flag is actuated by a fork with a handle below the case outside. To set the zero the left hand weight is placed with its pointer at the zero of the scale, and the flag is turned to one side or the other until it is found that, with no current going through the rings, the balance rests in its sighted position.

7. To measure a current the weight is slipped along the scale until the beam balances in its sighted position. The strength of the current is then read off approximately on the fixed scale (called the inspectional scale) with aid of the finely divided scale for more minute accuracy, according to the explanations given in § 11. Each number on the inspectional scale is twice the square root of the corresponding number on the fine scale of equal divisions.

8. The sliding of the weight into its proper position is performed by means of a self-releasing pendant hanging from a hook carried by a sliding platform, pulled in the two directions by two silk threads passing through holes to the outside of the glass case.

9. Four pairs of weights (sliding and counterpoise), of which the sledge and its counterpoise constitute the first pair, are supplied with each instrument. These weights are adjusted in the ratios of 1 : 4 : 16 : 64, so that each pair gives a round number of amperes, or half amperes, or quarter-amperes, or of decimal sub-divisions or multiples of these magnitudes of current, on the inspectional scale.

10. The useful range of each instrument is from 1 to 100

of the smallest current for which its sensibility suffices. The ranges of the different types of this instrument regularly made are:—

I. Centi-ampere Balance	: from	1 to 100	centi-amperes.
II. Deci-ampere	,, ,,	1 to 100	deci-amperes.
III. Deka-ampere	,, ,,	1 to 100	amperes.
IV. Hekto-ampere	,, ,,	6 to 600	,,
V. Kilo-ampere	,, ,,	25 to 2,500	,,
VI. Composite	,, ,,	·02 to 300	,,
,,	,, ,,	100 to 25,000	watts (at 100 volts).

The following table shows for each type of instrument the value per division of the inspectional scale corresponding to each of the three pairs of weights :—

	I. Centi-amperes per division.	II. Deci-amperes per division.	III. Amperes per division.	IV. Amperes per division.	V. Amperes per division.
1st Pair of Weights,	·25	·25	·25	1·5	5
2nd ,,	·50	·5	·5	3·0	10
3rd ,,	1·0	1·0	1·0	6·0	20
4th ,,	2·0	2·0	2·0	12·0	50

11. The fixed inspectional scale shows, approximately enough for most purposes, the strength of the current; the notches in the top of the aluminium scale show the precise position of the weight corresponding to each of the numbered divisions on the fixed scale, which practically annuls error of parallax due to the position of the eye. When the pointer is not exactly below one of the notches corresponding to integral divisions of the inspectional scale, the proportion of the space on each side, to the space between two divisions, may be estimated inspectionally with accuracy enough for almost all practical purposes. Thus we may readily read off 34·2 or 34·7 by estimation with little chance of being wrong by 1 in the decimal place. But when the utmost accuracy is required, the reading on the fine scale of equal divisions must be taken, and the strength of current calculated by aid of a table of doubled square roots. Thus, for example, if the reading is 292 we find 34·18, or say 34·2 as the true scale reading for strength of current; or again, if the balancing position of the pointer be 301 on the fine scale, we find 34·70 as the true reading of the inspectional scale.

12. The centi-ampere balance, with a thermometer to test

the temperature of its ampere rings, and with platinoid resistances up to 2,000 ohms, serves to measure potentials of from 10 volts to 200 volts.

Adjustment of the Standard Balances.

13. The instrument should be levelled in accordance with the indications of the attached spirit level, by means of the levelling screws on which the sole-plate of the instrument stands.

14. In the centi- and deci-ampere balances, the beam can be lifted off its supporting ligaments by turning a handle attached to a shaft passing under the sole-plate of the instrument. This shaft carries an eccentric, on the edge of which rests the lower end of a vertical rod, which is fixed at its upper end to a tripod lifter. When the instrument is to be packed for carriage, or when it is to be removed by hand from place to place, the lifter should be raised; but when it is fixed up for regular use it is advisable to keep the beam always hanging on the ligaments. In the deka-, hekto-, and kilo-ampere balances there is no lifter, but the beam is packed by placing distance pieces between the two halves of the suspension trunnions and screwing them together by means of milled-headed screws provided for the purpose. When the instrument is unpacked and prepared for use, these distance pieces must be taken out and placed in receptacles provided for them in the weight box.

15. A set of four sliding weights, of which the carriage constitutes one, is supplied with each instrument. The carriage is fitted with an index to point to the movable scale, and is intended to remain always on the rail. One or other of the weights is to be placed on the carriage in it in such a way that the small hole and slot in the weight pass over the conical pins. The weights are moved by means of a slider, which slides on a rail fixed to the sole-plate of the instrument, and which carries a pendant with a vertical arm intended to pass up through the rectangular recess in the front of the weight and carriage. The slider and weight are shown in position in the figures. The slider is moved by silk cords which pass out at the ends of glass case. When the cords are not being pulled for shifting the weight, their ends should be left free so that the pendant may hang clear of the weight. When a weight is to be placed on or removed from the carriage, the slider should be drawn forward at the top until it is clear of the weight, and then pushed to one side until the

weight is adjusted, when it may be replaced in position in a similar manner.

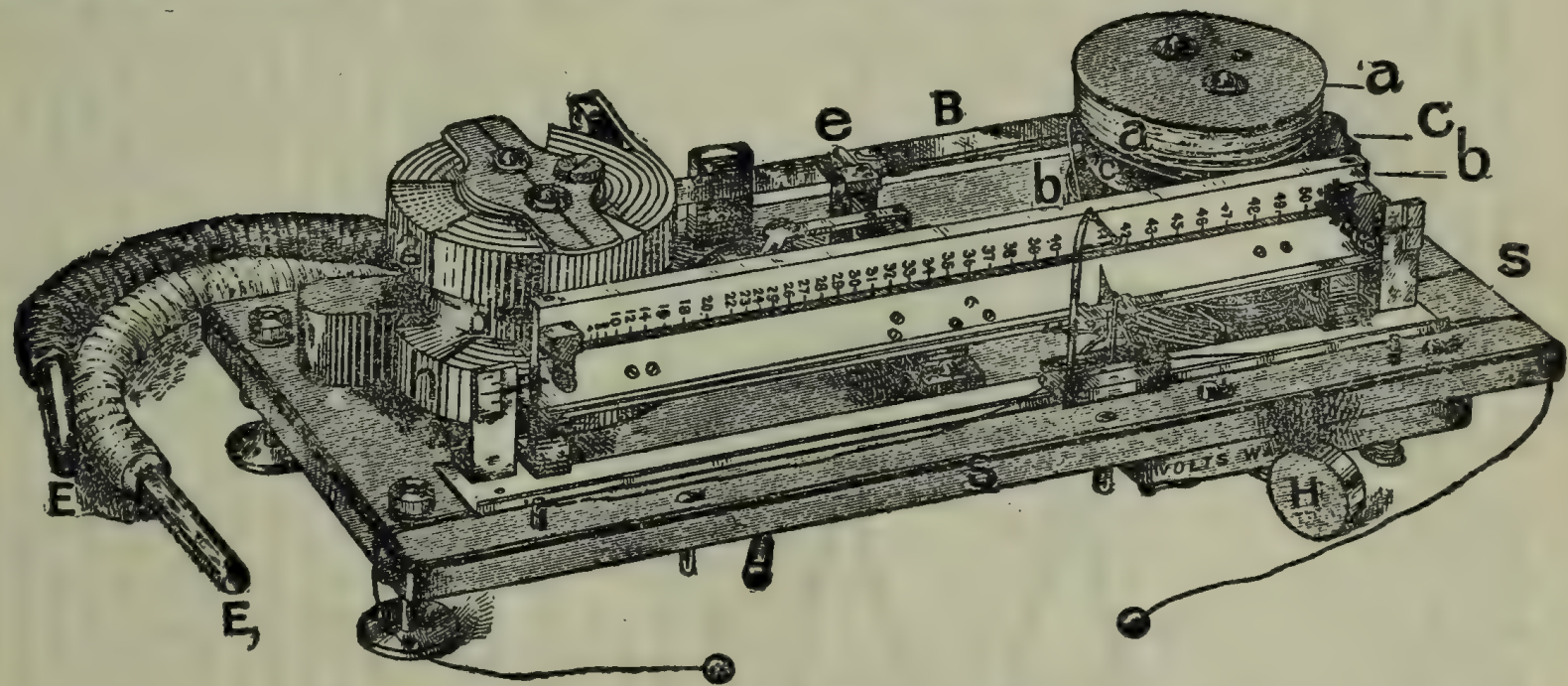
16. Cylindrical counterpoise weights with a cross-bar passed through them are supplied for the purpose of balancing the sliding weights when they are placed at the zero of the scale. The sliding weight should be plated so that the index of the carriage points to the zero of the scale, and the proper counterpoise weight should be placed in the trough, fixed to the right hand end of the beam, with its crossbar passing through the hole in the bottom of the trough. The flag which is attached to the cross trunnion of the beam should then be turned by means of the handle projecting from under the sole-plate, until the index on the end of the movable scale points to the middle one of the five black lines on the fixed scale opposite to it. Care must be taken when making this adjustment that the fork which moves the flag is not left in contact with it, as this would impede the free swing of the beam. The fork should be turned back a little after each adjustment of the flag, and, when the flag is being adjusted, it is better to watch the flag itself, and make successive small adjustments until the beam stands at zero, than to make successive trials by pushing round the handle while watching the position of the index.

17. When the centi-ampere balance is to be used as a voltmeter, care must be taken that the effect of change of temperature in changing the resistance of the coils of the instrument, and of the external resistance coils, is allowed for; and in this use of the instrument it is advisable to employ currents such as can be measured by the lightest weight on the beam. When the instrument is to be used as a voltmeter, four resistances are provided on a separate copper cylinder. Three of the four resistances are each 500 ohms, and the fourth is less than 500 ohms by the resistance of the coils of the instrument at a certain specified temperature. The smallest resistance is intended to be included by itself in the circuit when the lowest potentials are being measured, and in series with one or more of the others when the potential is so high as to give a stronger current than can be measured with the lightest weight on the beam. The correction for temperature is, for the copper coils of the balance, about 0·38 per cent. per degree centigrade, and for the platinoid resistances, about 0·024 per cent. per degree centigrade.

Use of the Composite Balance.

Composite Electric Balance.—This instrument has been designed for the purpose of providing in one piece of apparatus, the means of measuring—

(1) The difference of potential between two points of an electric circuit, as, for instance, the difference of potential between the supply conductors of an electric-light installation. (2) The current flowing in such a circuit. (3) The rate of working in the circuit. The instrument thus forms a combined voltmeter, ampere-meter, and watt-meter.



SIR WM. THOMSON'S COMPOSITE ELECTRIC BALANCE.

The general form of the instrument is shown in the first figure, and the theoretical diagram in the second figure. Where *a* and *b* are two coils of silk covered copper wire fixed one above

the other, with their planes horizontal, on a slab of slate, S. Two coils, *c* and *d*, of similar wire, are made up in form of anchor rings, and fixed to the ends of a balance beam, B, which is suspended by two flat ligaments, *e* and *f* (hidden by scale in 1st Fig.), of fine copper wires, in such a position that one of the coils fixed to the ends of the beam is sus-

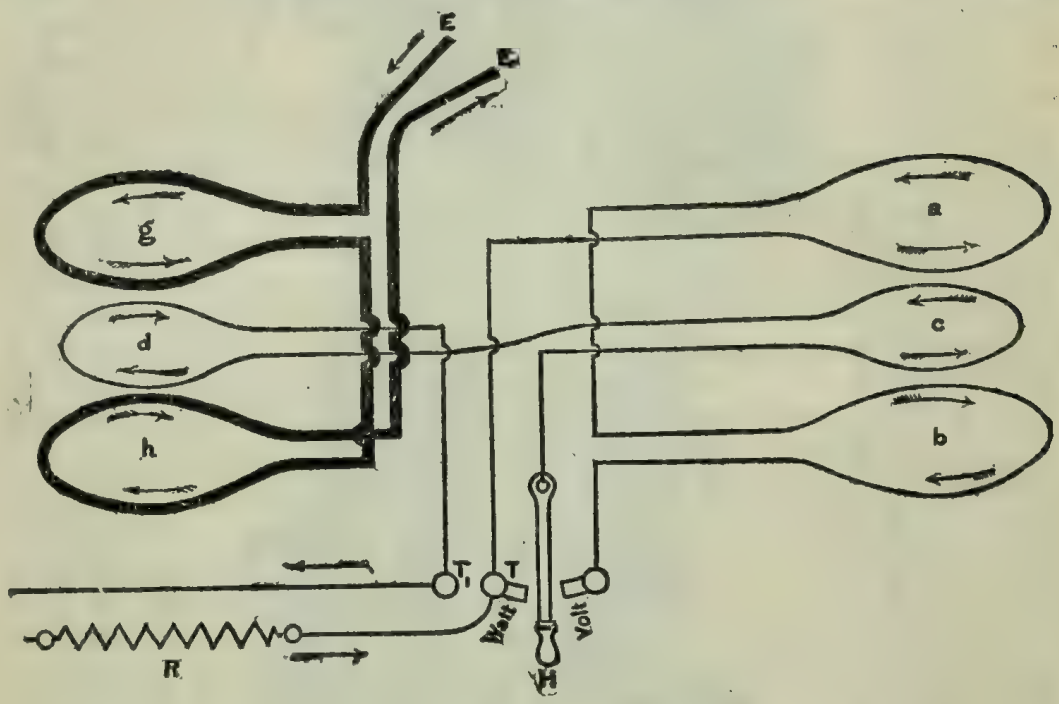


DIAGRAM OF THE COMPOSITE BALANCE, COILS, &c.

pended mid-way between the coils, *a* and *b*, with its plane parallel to the planes of these coils, and with its centre in the line joining the centres of them. Other two coils, *g* and *h*, capable of carrying strong currents, are fixed to the sole-plate, S, in positions which, relatively to *d*, are similar to those occupied by *a* and *b* relatively to *c*. When the instrument is to be used for the measurement of continuous currents, the coils *g* and *h* are made of several turns of thick copper ribbon, capable of carrying currents up to a maximum strength of 500 amperes. When it is to be used for the measurement of alternating currents these coils are made of two or three turns of a stranded copper conductor. Each wire of the stranded conductor is covered with silk, so as to insulate it from the others, and, in order as far as possible to annul the effect of induction in causing the current to be different at different distances from the axis of the conductor, the strand is given one turn of twist for each turn round the coil.

To set the Instrument (see 2nd Fig.)—The balance should be levelled and the stop screws turned back out of contact

with the cross trunnion and the front plate of the beam so as to leave it free to oscillate.

For the measurement of Potentials, that is to say, as a Voltmeter or as a Centi-ampere Meter.—It is connected to the circuit through a suitable resistance, R, wound anti-inductively, through which the current passes to the terminal, T, from which the course of the current through the coils to T_1 is indicated by the arrows in the diagram; the switch handle, H, being in this case turned to "Volt," and one or other of the weights marked v. w_1, v. w_2, v. w_3, used. The current flowing through the instrument is then to be calculated from the constant given in the certificate sent with the instrument. The volts on the terminals are calculated from the current in amperes and the resistance in ohms (including the anti-induction resistance, if any) in circuit. If V be volts, C current, and R resistance,

$$V = C R.$$

To use the Instrument as a Hekto-ampere Meter.—The switch is turned to "Watt" and the thick wire coils inserted in the current circuit in such a way that the right hand end of the beam is repelled up. Either the sledge alone or the weight marked w. w. is to be used in this case. A measured current is then passed through the suspended coils, *g* and *h*, by introducing the electrodes, E and E_1, into the circuit, and the constants given in the certificate for the balance used in this way are calculated on the assumption that this current is, as there stated, 0·25 amperes. Any other current which is convenient in the circumstances may be used, and if this current be, C, amperes the corresponding constant is obtained by multiplying the constant given in the certificate by C/·25 or 4 C. The current through the suspended coils may be measured by means of the instrument itself arranged for the measurement of volts. This may be done by first measuring the current which the difference of potential between the supply-conductors of an electrical installation, or between the poles of a battery, causes to flow through the coils of the instrument and its external resistance, and then turning the switch to "Watt," and at the same time introducing a resistance into the circuit equal to the resistance of the fixed coils.

To use the Instrument as a Watt-meter.—One terminal of the fine wire coils is joined to one end of the anti-inductive resistance, R, and the other terminal to one of the leads; the other end of the resistance being joined to the other lead. The thick wire coils are inserted in the main circuit as described above. With the instrument thus joined up, the current through the suspended coils and the e.m.f.

between the leads may be obtained by the operations described above, since the presence of the thick wire coil in the circuit causes no appreciable error: or the e.m.f. may be taken from the electrostatic voltmeter used on the circuit, and from its indications the current in the suspended coil circuit calculated. The Watts are then to be calculated from the e.m.f. on the leads and the current through the thick wire coils by the formula,

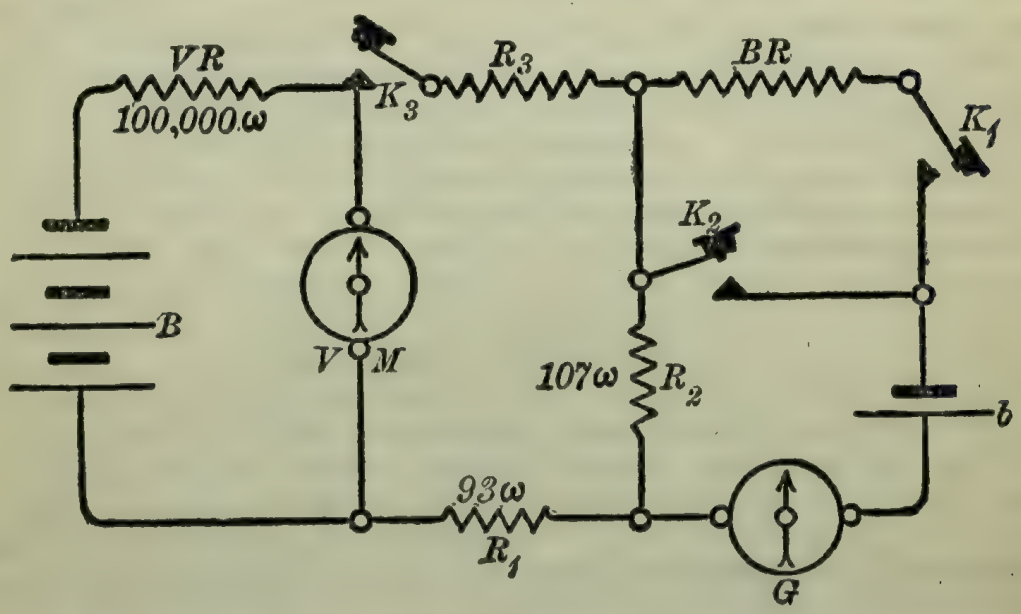
$$P_W = V\,C = c\,C\,R.$$

Where, c, is the current in the suspended coil circuit,
" C, is the current in the thick wire coils,
" R, is the resistance in the circuit.

When the rate of working in an alternate-current circuit is measured by such a balance, the anti-inductive resistance, R, must be so great that there is no sensible difference of phase between the currents flowing through the fine wire coils of the instrument and the electromotive force on the supply-conductors to which they are connected.

Calibration of Voltmeters.

For this purpose in the following test, Dr. Fleming's form of Standard Daniell cell * is used with electrodes of pure zinc in solution of pure zinc sulphate, sp. gr. 1·4, and pure freshly electrotyped copper rod in solution of pure copper sulphate, sp. gr. 1·1. This cell at the temperature of 60° F. has an E.M.F. of 1·070 true or Rayleigh volt.



* See Dr. Fleming's "Lectures to Electrical Artisans" (E. & F. Spon), p. 161.

The arrangement is, in principle, the same as that suggested by Swinburne in the *Electrical Review*, 1887.*

Index to Diagram.

V M for voltmeter to be calibrated.
B ,, battery of storage cells or dynamo.
V R ,, variable high resistance.
R_1 ,, resistance = 93 ohms.
R_2 ,, resistance = 107 ohms.
R_3 ,, resistance in the, R, part of wheatstone bridge.
B R ,, resistance of one arm, *b*, of bridge (arm, *a*, being plugged up).
K_1, K_2 ,, keys of wheatstone bridge.
K_3 ,, key to be depressed *only* when finding a balance to prevent heating, R_1, R_2, R_3.
b ,, Fleming's standard cell = 1·07 *v*.
G ,, Galvanometer (deadbeat mirror).

The bridge arms are of the usual form. The other coils of bridge are most convenient if arranged upon the decimal system, but with central arms like the slides having all rubbing contacts of platino-iridium. This plan permits of very rapid adjustment and reading. The variable resistance, V R, may be of German silver or platinoid. and preferably arrange decimally with rotating arm and central contact. As these resistance coils have often to carry currents of high pressure, the usual practice of winding has been abandoned in favour of that described under heading Resistance Coils. See Index for Winding Bobbins.

The coils, R_1, R_2, R_3, are all of platinum silver. These resistances should always be of same material, so as to vary equally with temperature, and the coefficient for temperature should be known, so as to get true ohms.

Instructions for Taking Test.—Suppose we desire to obtain 100 volts on voltmeter, make R_3, = 9,800 ω.

Then $R_1 + R_2 + R_3 = 10{,}000$ ohms.

Consequently, $\frac{10{,}000\,\omega}{100\,v} = 100\,\omega$ per volt.

Since we have the cell, *b*, = 1·07 volts joined up to ends of, R_2,

$$\frac{107\,\omega}{1{\cdot}07\,v} = 100\,\omega \text{ per volt.}$$

Therefore, vary, V R, until no deflection is obtained from G, on depressing, K_3, and, K_2, *i.e.*, until we get a balance.

* The method and apparatus here described, is that adopted by Messrs. M'Whirter, Ferguson & Co, in calibrating their voltmeters, and is found to be handy and accurate.

The fall of potential throughout, R_1, R_2, R_3, is now at the rate of 100 ohms per volt, or the voltmeter reads 100 volts.

It will be observed that, K_1, is joined up in circuit with resistance, B R, = 1,000 or more ohms, and this key should always be used instead of, K_2, until the deflection on, G, is very small, so as to prevent sending a strong current through, G, and, *b*.

Should any other voltage, E, be required on the voltmeter, we have simply to make

$$R_1 + R_2 + R_3 = 100\ E,$$

and vary, V R, until we get a balance as before.

Should it be required to check a voltmeter that has already been calibrated, then—

1. Obtain the desired reading on the voltmeter by varying, V R, and;
2. Adjust, R_3, until no deflection is obtained on, G, when the *true* volts

$$E = \frac{R_1 + R_2 + R_3}{100}.$$

Standardising Current Meters* by Electro-Deposition of Copper.

Solution.—Fill a glass or stoneware jar with a solution of $CuSO_4$, having a specific gravity between 1·15 and 1·18, so as to give about 70 cubic inches per ampere required; or, take a saturated solution of $CuSO_4$ (sp. gr. 1·21) and add 1 volume of water to 5 parts of this, with about 1°/₀ of H_2SO_4, if the solution is not sufficiently acid from the copper sulphate.

Gain Plates.—Take pure or high conductivity copper plates, 30 to 36 S.W.G. (the same as often supplied for dynamo brushes) for the cathode or gain plate. Cut the plates to the depth of the jar, and bend the upper ends, ∩. Arrange the number of gain plates so that the total superficial area immersed in $CuSO_4$, reckoning both sides of plates, shall not be less than 12 square inches per ampere.

Loss Plates.—Take high conductivity copper plates of 16

* See *Proceedings of Philosophical Society of Glasgow* for 1887-88; *The Electrical Review*, 1888; *The Electrician*, 1888; *The Electrical Engineer*, 1888: for a paper by A. W Meikle on "The Electrolysis of Copper Sulphate in Standardising Electrical Instruments; also, a paper by Thomas Gray, B.Sc., *Philosophical Magazine*, Nov., 1886.

to 20 S.W.G. Cut and bend them in the same way as the gain plates. Place the gain and loss plates so,— L G L where, L, L, stands for loss plates or anodes, and, G, for the gain plate. In other words each gain plate must have a loss plate on each side of it whatever may be the number of gain plates. The loss plates must be connected together, and if more than one gain plate is required the gain plates must be connected together.

Suspending Plates.—Suspend the plates from clean stout copper wires so that the ∩ of the plates will clip the wires tightly. These wires to be so placed across the top of the jar that the gain plates are about ¾″ apart from the loss plates.

Preparing Plates.—All corners to be carefully rounded. The plates to be thoroughly cleaned by polishing them with fine, clean, dry glass paper, No. 1, and then dusted with a sash-tool brush or silk cloth, taking care not to touch any part of the plates to be immersed with the fingers. This cleaning process should be done *immediately* before use.

Trial Gain Plates.—Two sets of gain plates should be prepared exactly alike in every respect. One set to be used simply for preliminary trial or adjustment of current.

Rheostat.—Either use Sir William Thomson's system of conductivity bridge and rheostat, or take a teak board 1¼″ thick by 12″ broad by say about 3 ft. long, and run parallel longitudinal, V grooves ½″ wide at top × ½″ deep × not less than ¾″ between centres along this board, stopping the grooves at each end by gluing in V blocks of wood. Pour mercury into each groove to a depth of ¼″. By means of, ∩, copper bridges any desired length or mercury resistance may be brought into circuit, or if need be joined up in parallel.

Making the Test.—Join up in one continuous circuit the current meter to be calibrated or standardised, with sufficient battery power or accumulators, to give the required current, the rheostat and electrolytic cell or cells having the one set of trial plates in position. Now adjust the rheostat until the required current or deflection is obtained. Then remove the trial plates having, just previously, carefully weighed the second set of gain plates. Insert this second set of gain plates, and keep the deflection exactly the same as before by the rheostat, noting the exact second when they were brought into circuit with the current. Keep the current constant for not less than half-an-hour, noting the exact second when the current is stopped.

Now remove the gain plates quickly from the electrolytic cell, placing them immediately in a glass vessel of pure water slightly acidified with, H_2SO_4, to prevent oxidation. From this take them one at a time and rinse them in pure water and dry them carefully between white, warm blotting paper, completing the drying before a fire or gas flame (not *over* fire or gas).

When cool, carefully weigh the whole of the gain plates, and note the total increase of weight.

Estimating the current.—If the gain plate area has been at the rate of 7·7 square inches per ampere and the temperature 12°C., or if the gain plate area be at the rate of 23·1 square inches per ampere and the temperature 2°C., then—

$$\text{The amperes} = \frac{\text{Weight gained in grains per hour}}{18{\cdot}261}.$$

Or, for any other current density and temperature use the following Tables.

TABLE OF ELECTRO-CHEMICAL EQUIVALENTS OR GRAMMES DEPOSITED PER SECOND.

Area of Cathode in Square Centimetres per Ampere of Current.	Temperature, 2° C.	Temperature, 12° C.	Temperature, 23° C.	Temperature, 28° C.	Temperature, 35° C.
	Grammes per Second.				
50	·0003288	·0003287	·0003286	·0003286	·0003282
100	·0003288	·0003284	·0003283	·0003281	·0003274
150	·0003287	·0003281	·0003280	·0003278	·0003267
200	·0003285	·0003279	·0003277	·0003274	·0003259
250	·0003283	·0003278	·0003275	·0003268	·0003252
300	·0003282	·0003278	·0003272	·0003262	·0003245

TABLE SHOWING GAIN AT CATHODE IN GRAINS PER HOUR PER AMPERE OF CURRENT, WHEN THE TEMPERATURE AND CURRENT DENSITY PER SQUARE INCH IS KNOWN.

Square inches of Cathode per Ampere.	Current Density per Square Inch of Cathode.	Cu deposited per Ampere per hour in Grains, at 2° C.	Cu deposited per Ampere per hour in Grains, at 12° C.	Cu deposited per Ampere per hour in Grains, at 23° C.	Cu deposited per Ampere per hour in Grains, at 28° C.	Cu deposited per Ampere per hour in Grains, at 35° C.
7·7	·13	18·266	18·261	18·256	18·256	18·233
15·4	·065	18·266	18·244	18·239	18·228	18·189
23·1	·043	18·261	18·228	18·222	18·211	18·150
30·8	·0325	18·250	18·217	18·205	18·189	18·105
38·5	·0260	18·239	18·211	18·194	18·155	18·066
46·2	·0217	18·233	18·211	18·136	18·122	18·028

Modes of using Ayrton and Perry's Secohmmeter.

This instrument consists of two rotatory commutators, each with four stationary brushes. The commutators are on the same spindle, one at the front, and the other at the back of the secohmmeter, but for convenience they are shown in the accompanying symbolical figures as if they were in the same horizontal plane; in reality, however, the brushes, b_1, b_2, b_3, b_4, are at the top of the instrument. One commutator, G C, is for periodically reversing the galvanometer connections, and the other, B C, for reversing the battery connections. An adjustment is provided for enabling the relative positions of the two commutators to be varied so that both reversals can be made to occur simultaneously, or one a little before or after the other, or one reversal midway between two successive reversals of the other.

The commutators can be driven at one or other of two speeds relatively to that of the driving handle, H. With one arrangement there are rather more than 8 reversals of both the galvanometer and of the battery for one revolution of the handle, and with the other 24 reversals of each for one revolution of the handle. The secohmmeter can be conveniently driven by hand so as to obtain a steady speed of 300 to 6000 reversals per minute of both the galvanometer and the battery.

To shift from one speed ratio to the other, press down the end of the locking lever at the right of the secohmmeter, and slightly push in or pull out the handle, turning it slightly to assist the toothed wheels engaging properly; when engaged, let go the end of the locking lever.

1. *To compare two Coefficients of Self-Induction.*—Join up the apparatus as in figure 1.* then, if the resistances, r_1, and, r_2, of the non-inductive branches of the bridge be adjusted

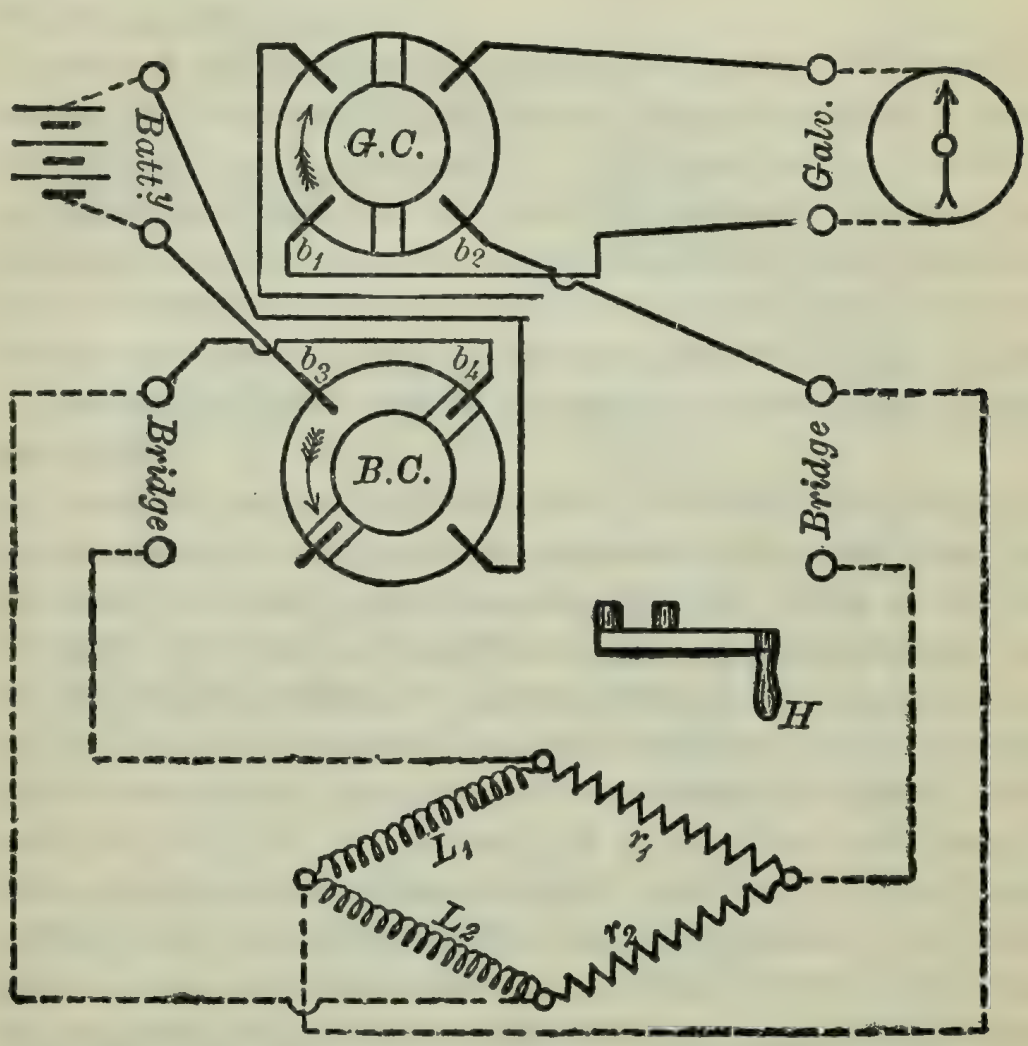


FIG. I. COMPARING TWO COEF. OF SELF-INDUCTION.

to give balance with a steady current, balance will also be obtained on rotating the secohmmeter, when

$$\frac{L_1}{L_2} = \frac{r_1}{r_2},$$

L_1, L_2 being the coefficients of self-induction of the in-

* The continuous lines represent the permanent connections in the secohmmeter itself, the dotted lines, connections temporarily made outside the instrument.

ductive branches. The speed at which the secohmmeter is driven need not be known, but the greater the speed the more sensitive the test; the rate of reversal must not, however, be too great for the currents to reach their steady values between two consecutive reversals.

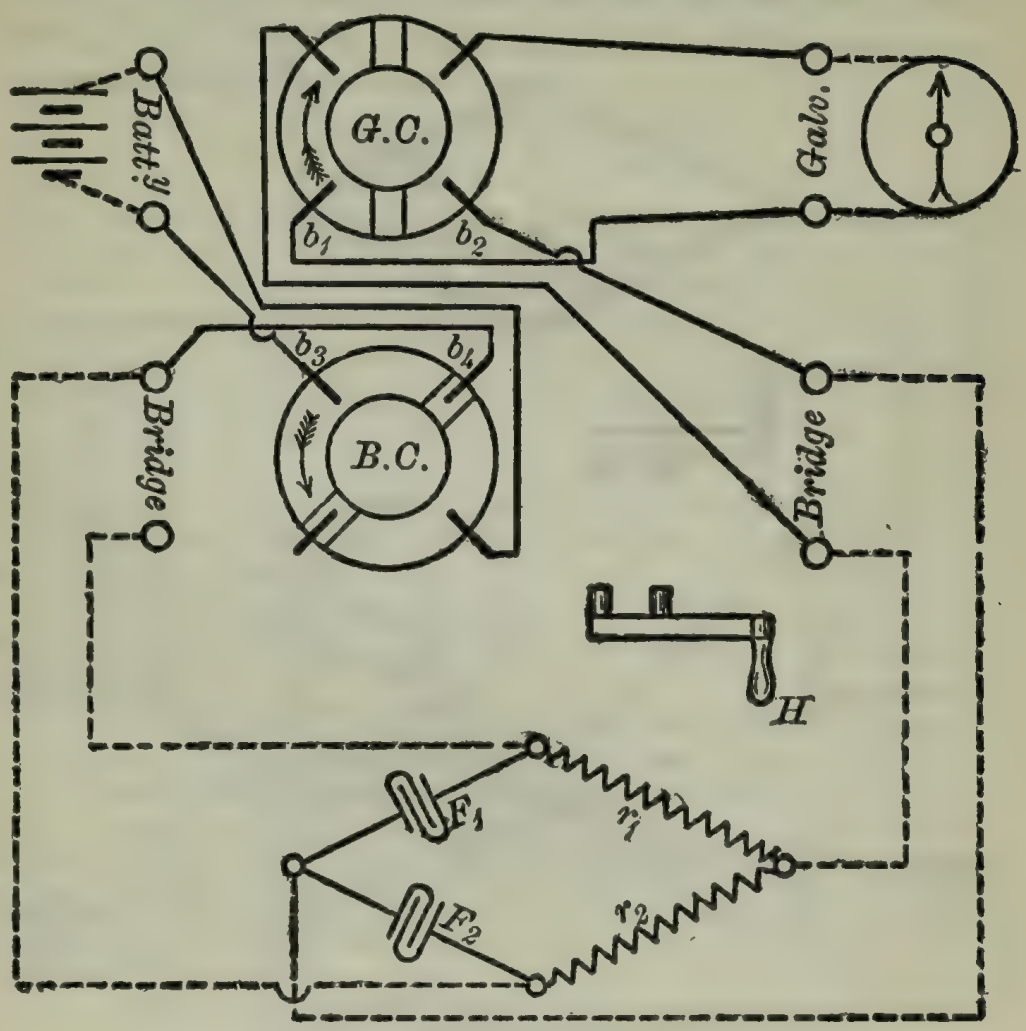


FIG. 2. COMPARING TWO CAPACITIES.

2. *To compare two Capacities.*—Join up the apparatus as in figure 2, then balance will be obtained on rotating the secohmmeter, when

$$\frac{F_1}{F_2} = \frac{r_2}{r_1},$$

F_1 and F_2 being the capacities of the condensers, and r_1 and r_2, the resistances of the non-inductive branches of the bridge. As before, increasing the speed at which the secohmmeter is driven merely increases the sensibility

of the test without affecting the ratio connecting the capacities with the resistances.

3. In similar ways two coefficients of mutual induction may be compared with one another, or a coefficient of mutual induction with a coefficient of self-induction, or either of these coefficients with the capacity of a condenser shunted by a non-inductive resistance. See various papers that have already appeared on the theory of the secohmmeter.

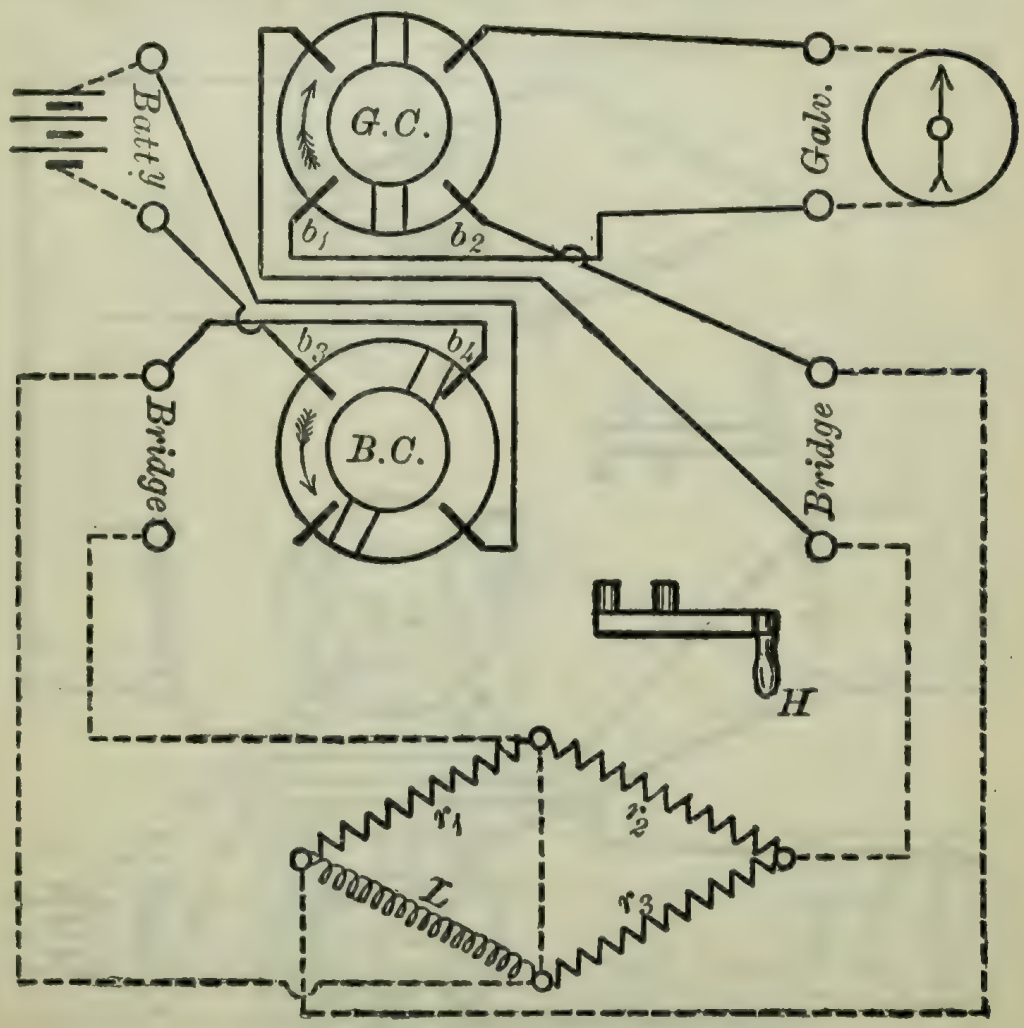


FIG. 3. MEASURING COEF. OF SELF-INDUCTION IN SECOHMS.

4. *To measure a Coefficient of Self-Induction absolutely in Secohms.* (*a.*) *Comparative deflection method.*—Attach a speed indicator to the commutator spindle, which is prolonged for this purpose, and join up the apparatus as in figure 3, L being the coefficient of self-induction to be measured, and r_1, r_2, r_3, values of the three non-inductive resistances

that give balance with a steady current. Rotate the secohmmeter handle at some convenient speed, causing the commutator spindle to make n revolutions per second, and observe the steady deflection. d_1, of the galvanometer. Next stop the secohmmeter, and increase or diminish one of the resistances, r_1, for example, by a small amount, ρ ohms obtaining a steady deflection, d_2, of the galvanometer with the battery previously used; then

$$L = \frac{d_1}{d_2} \cdot \frac{r_3}{r_2} \cdot \frac{\rho}{8n}, \text{ secohms, approximately.}$$

For this test the relative positions of the two commutators is unimportant. They may be as in figures 1 and 2, in which case the reversal of the galvanometer occurs midway between two consecutive reversals of the battery, or they may be as in figure 3, in which case the reversal of the galvanometer just precedes the reversal of the battery. The greater the value of n, the greater will be the deflection, d_1, and the more accurately can it be read, but the speed must not be too great to prevent the currents reaching their steady values between two consecutive reversals of the battery. Whether this condition be fulfilled or not, can be best ascertained by seeing whether the same value is obtained for L, for a speed considerably smaller than n.

(*b.*) *More sensitive Zero method.*—Instead of obtaining two deflections, the resistances, r_1, r_2, r_3, are first adjusted to give balance with a steady current, and then one of them, say r_1, is altered by an amount, σ ohms, so that there is still no deflection of the galvanometer when the commutator spindle makes, say n revolutions per second; then

$$L = \frac{r_3}{r_2} \sigma \frac{k}{n}, \text{ secohms, approximately,}$$

where k is a constant, depending on the relative position of the commutators. The value of the constant, k, is most accurately ascertained once for all, for a given relative position of the commutators by experimentally determining the value of $\frac{r_3}{r_2}\sigma$, that produces balance for a known coefficient of self-induction, when the commutator spindle is driven at some known number of revolutions per second.

For this test, *b*, it is necessary that the commutators be so placed relatively to one another that the galvanometer

is not reversed exactly midway between two consecutive reversals of the battery, since with this latter adjustment no variation in the resistance of any of the arms of the bridge can counterbalance the effect of the self-induction on rotating the secohmmeter handle; in fact, the more nearly the commutators are placed in the midway adjustment, the smaller will be the value of k, and therefore the larger the value of $\frac{r_3}{r_2}\sigma$, to produce balance for given values of L and n.

5. *To measure the Resistance of a Polarisable Electrolyte*—Replace the coil having self-induction in figure 3, by the polarisable electrolyte, adjust the commutators so that the galvanometer is reversed just before the battery, and, using the higher speed ratio for the gearing, rotate the secohmmeter at the highest convenient speed. Then if x be the true resistance of the electrolyte,

$$x = \frac{r_3}{r_2} r_1.$$

ELECTRO-MOTIVE FORCE.

The electro-motive force of a battery is the difference of potentials between its poles *when no current is passing through or from it.* It can be measured directly by the Thomson absolute electrometer; but in practice it is usually compared with the E.M.F. of another battery.

By Quadrant Electrometer.—Connect one pole of the battery to one pair of quadrants, and also to the case of the instrument and induction plate electrode on the "main cover:" then connect the other pole to the other quadrants, which must be kept insulated. Let d be the deflection so obtained; then

$$E = d \times \text{constant},$$

where E = electro-motive force in volts.

The constant depends on the instrument employed. If the battery is compared with a standard cell of known electro-motive force, E_s, giving a deflection, d_s; then

$$E = E_s \cdot \frac{d}{d_s} \quad . \quad . \quad . \quad . \quad \text{volts.}$$

N.B.—A galvanometer with a condenser and key in circuit (see p. 111) may replace the electrometer. Compare the discharge with that from a standard cell.

Equal Deflection Method.—Let E_1, E_2, be the electro-motive forces of the two batteries to be compared. 1. Join E_1 through a galvanometer and resistance, R_1, and take the deflection. 2. Join E_2, through the same galvanometer, and resistance R_2, which gives an equal deflection. Then if G = res. of galv., and B_1, B_2, that of the batteries,

$$E_2 = E_1 \frac{R_2 + G + B_2}{R_1 + G + B_1}, \text{ or approx. } E_2 = E_1 \frac{R_2}{R_1} \text{ volts.}$$

When a shunt, s_2, to the galvanometer, G, is employed with the larger battery, E_2:—

$$E_2 = E_1 \frac{R_2 \dfrac{G + s_2}{s_2}}{R_1}$$

When shunts are used for both measurements,

$$E_2 = E_1 \frac{R_2 \dfrac{G + s_2}{s_2}}{R_1 \dfrac{G + s_1}{s_1}}$$

These two formulæ are only true when, R_1, and, R_2, are so large relatively to the other resistances in circuit, that the res. of galvanometer, shunts, and batteries are negligible.

EQUAL RESISTANCE METHOD.—When the resistances of the two batteries, E_1, E_2, are known,—1. Join up E_1 in circuit with a galvanometer and resistance, R_1, and take deflection, d_1. 2. Substitute E_2 for E_1, and change R_1 to R_2, so as to make the total resistance in circuit the same as before; and take deflection d_2. Then,

$$E_2 = E_1 \frac{d_2}{d_1} \quad . \quad . \quad . \quad \text{volts.}$$

If the resistances of the batteries are very small as compared with R_1 and R_2 they may be neglected, provided the galvanometer is sensitive.

WHEATSTONE'S METHOD.—1. The battery E_1 volts, in circuit with R_1 ohms, gives a deflection d_1. By adding r_1 ohms the deflection is reduced to d_2.

2. The battery E_2 volts, in circuit with R_2 ohms, gives a deflection, d_1. By adding r_2 ohms this is reduced to d_2. Then,

$$E_2 = E_1 \frac{r_2}{r_1} \quad . \quad . \quad \text{volts.}$$

R_1 should be as high as possible, and r_1 as nearly equal to it as possible.

WIEDEMANN'S METHOD.—1. The batteries E_1 and E_2 of resistances R_1 and R_2 are connected in circuit with a tangent galvanometer of resistance, r, so that their currents go the same way, and give a sum current, $C_s = \frac{E_1 + E_2}{R_1 + R_2 + r}$.

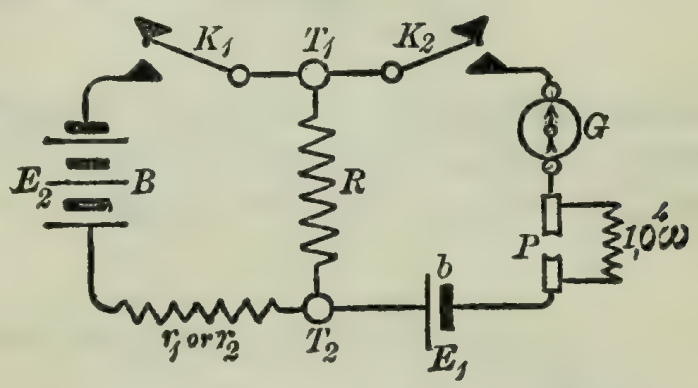
2. The batteries are reversed, so that their currents go in opposite directions through the galvanometer, and give a difference current.—

$$C_d = \frac{E_1 - E_2}{R_1 + R_2 + r}.$$

Then

$$E_2 = E_1 \frac{C_s - C_d}{C_s + C_d} \quad . \quad . \quad . \quad \text{volts.}$$

POGGENDORFF'S METHOD.—The terminals, T_1, T_2, as in fig., form the common junction of three circuits—1st, the larger battery, B; 2nd, the adjustable resistance, R; 3rd, the standard cell, *b*, and galvanometer, G.



Let E_1 = E.M.F. of standard cell (*known*).
b = Res. ,, ,, not required.
E_2 = E.M.F. of large battery (*required*).
B = Res. ,, ,, in ohms.
r_1 or r_2 = Res. in circuit with B when wanted.
P = Plug for bringing 10000 ω into circuit to guard, *b*, if it is a Clark cell.
K_1, K_2 = Keys.

If we know B, leave out r_1 or r_2, and adjust, R, until no deflection is shown on, G, with K_1 and K_2 depressed. Then

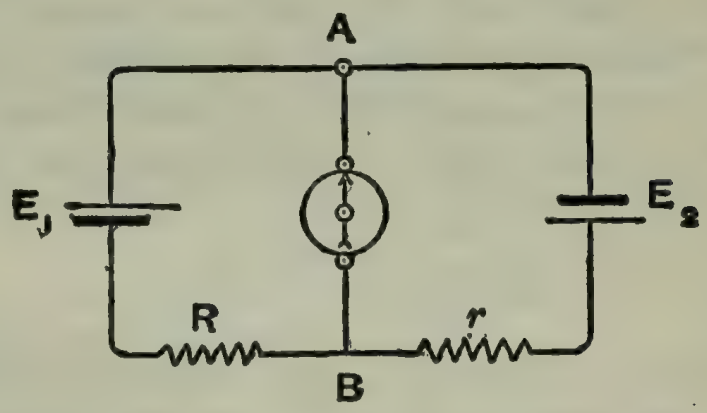
$$E_2 = E_1 \frac{R + B}{R} \quad . \quad . \quad . \quad \text{volts.}$$

If, *b*, should be a daniell cell, or one that does not run down in E.M.F., then put in plug, P, and balance again.

When, B, is *not* known, insert a resistance, r_1, in the circuit of E_2, and adjust R as before, to give nil on the galvanometer. Change r_1 to r_2, and R to R_1 until a balance is re-established. Then

$$E_2 = E_1 \frac{(r_1 - r_2) + (R - R_1)}{R - R_1} \quad . \quad . \quad \text{volts.}$$

LACOINE'S METHOD.—The two batteries are joined up with their opposite poles connected as shown in the fig., and with resistances, R, r, in circuit. A galvanometer is connected between the points, A B. One of the resistances, say r, being fixed, the other, R, is adjusted till no deflection is observed on the galvanometer.



Then, $\frac{E_1}{E_2} = \frac{R}{r}$ and $E_2 = \frac{E_1 r}{R}$ . . volts.

The resistances of the batteries are supposed to be inappreciable as compared with the high resistances R, r. Otherwise they must be added to R and r. The test is most accurate when R is the highest resistance in which a change of one unit from its correct value produces a readable deflection; and when r is as high as possible, but not so high that

$$r \left\{ G \left(1 + \frac{E_2}{E_1}\right) + r \right\}$$

exceeds $\frac{E_2^2}{E_1 c}$; where c is the figure of merit of the galvanometer (p. 70), and E_2 is the stronger battery.

LAWS' METHOD.—1. Join up standard battery with discharge key and condenser ($\frac{1}{3}$ to 1 microfarad), charge condenser by depressing key, and discharge it through galvanometer by releasing key; note deflection and resistance of shunt, s_1, used with the galvanometer of resistance, G.

2. Introduce the battery whose E. M. F. is desired in place of standard battery, and effect the same operation, adjusting the shunt to s_2 until the same deflection is obtained as in former case.

Then,

$$E_1 : E_2 :: \frac{G + s_1}{s_1} : \frac{G + s_2}{s_2} \quad . \quad \text{volts.}$$

If a suitable deflection is obtained, using no shunt with standard battery, then, on obtaining the same deflection with the other battery,

$$E_2 = E_1 \frac{G + s_2}{s_2} \quad . \quad . \quad \text{volts.}$$

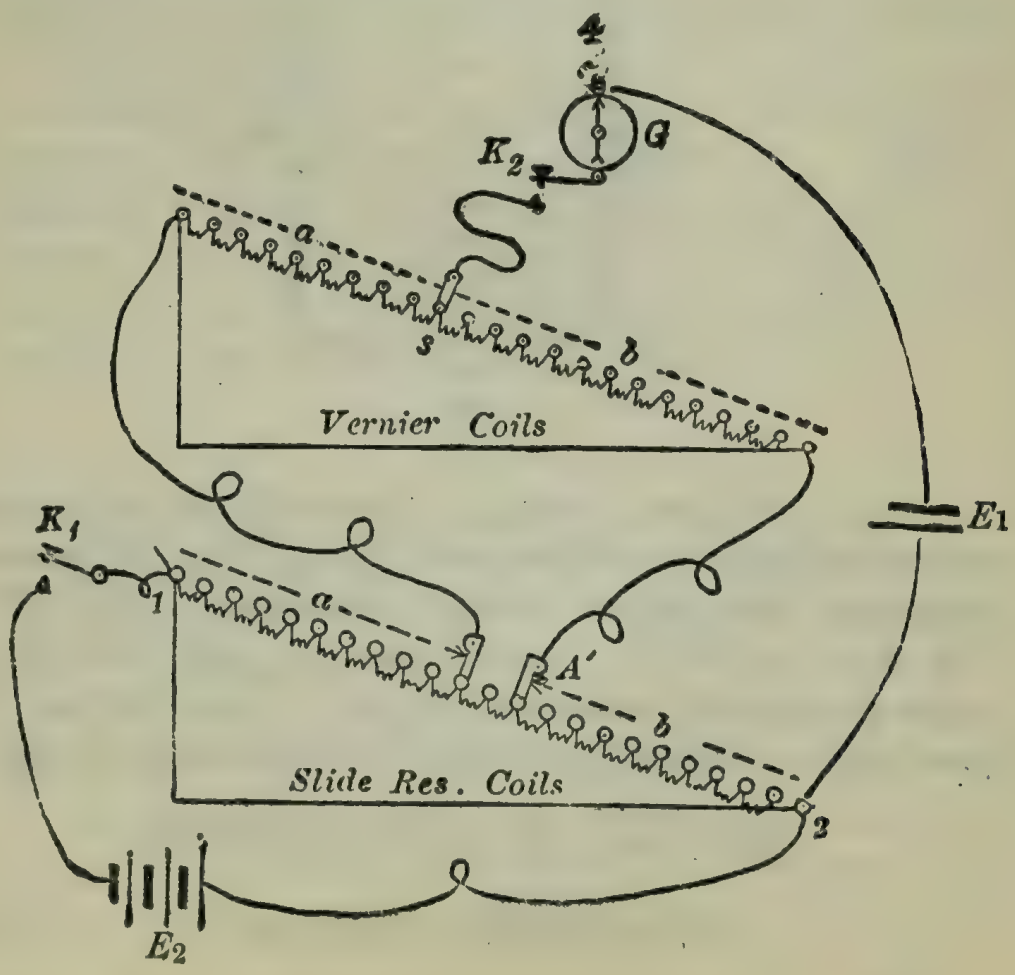
Or, the unknown electro-motive force equals the known into the multiplying power of the shunt used.

When comparing large with small electromotive forces, charge the condenser with the small battery first.

The same deflection can be got from both batteries without altering the shunt, if the batteries are joined in turn through a resistance so high, that we may neglect the battery resistance and the discharges taken from intermediate points of it. Then $E_1 : E_2 :: R_1 : R_2$, where R_1 and R_2 are the resistances between the intermediate points in either case. This test is conveniently made with the slides.

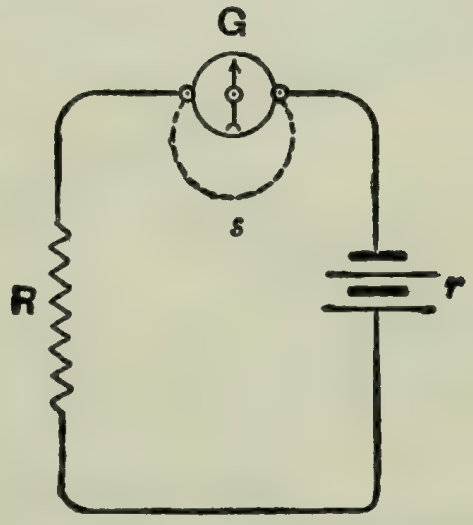
3. Slide Method.—(See the fig.)—Let the current from the larger battery, whose E.M.F., E_2, is required, flow directly through the slide res. coils from 1 to 2, a similar pole of the standard battery, E_1, being next the slides. Then, depressing K_2 for an instant at a time, move the contact pointers to right or left, until no deflection is obtained on the galvanometer; when the potential on each side of the galvanometer will be equal.

Therefore, $E_2 = \frac{10,000}{a} E_1$ volts, a being the reading on the slides. G may be an electrometer or high res. galvanometer.



RESISTANCE OF WIRES.

By Substitution.—*Simple Method.*—Connect the resistance, R, to be measured in circuit with a battery and mirror galvr., G, as in the fig. Note the deflection, then substitute another resistance, R_1, for R, and adjust it till the same deflection is obtained. Then $R = R_1$.



When the same deflection is not reproduced, but a different one, we have

$$R = \frac{d^1}{d}(R_1 + r + G) - (r + G),$$

where d = deflection got with R in circuit,
d_1 = ,, ,, R_1 ,,
G = resistance of galvanometer,
r = ,, of battery.

When r is so small compared with R, R_1, and G, as to be neglected, we have

$$R = \frac{d_1}{d}(R_1 + G) - G.$$

Shunt Method.—Connect a sensitive galvanometer, G, in circuit with a single cell and a high resistance, R (see fig., p. 91). Shunt the galvanometer with a standard resistance, s_1, by mercury cups, and note deflection, d_1. Then for s_1 substitute the resistance to be measured, s, and note deflection, d. We have

$$\frac{s}{s_1} = \frac{d}{d_1}, \text{ and } s = s_1 \cdot \frac{d}{d_1}.$$

The resistances, s and s_1, are supposed to be very low as compared with G and R.

Mercury Joints.—In measuring low resistances, their connections should be made with mercury cups. The ends of the wires should be well scoured with emery paper, and rubbed with nitrate of mercury before being dipped in the cups.

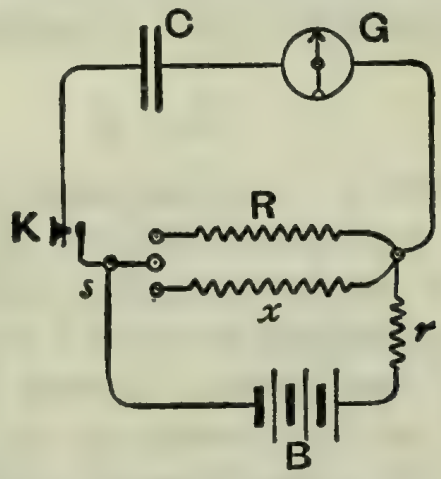
By Quadrant Electrometer.—Connect the resistance, R, to be measured in circuit with a battery and a known resistance, R_1. Join the ends of R to the quadrant terminals of an electrometer, and note the deflection, d. Next, join the ends of R_1 to the quadrants instead of R, and note the deflection, d_1. Then,

$$R = R_1 \cdot \frac{d}{d_1}.$$

A galvanometer of very high resistance, or one with condenser in circuit, is equivalent to a quadrant electrometer for this and other tests, except insulation resistance.

Nil Method.—Connect a battery, B, in circuit with a galvanometer, G, and condenser, C, as shown in the fig. Join the resistance, x, to be measured, and an adjustable resistance, R, as shunts to the battery; employing a key

or switch, *s*, to throw in one shunt after the other ; and a key, K, to make contact with the galvanometer. Then throw in *x*, and close K, to charge the condenser. Next, open K, and throw in R, then close K. If R is adjusted equal to *x*, there will be no deflection.

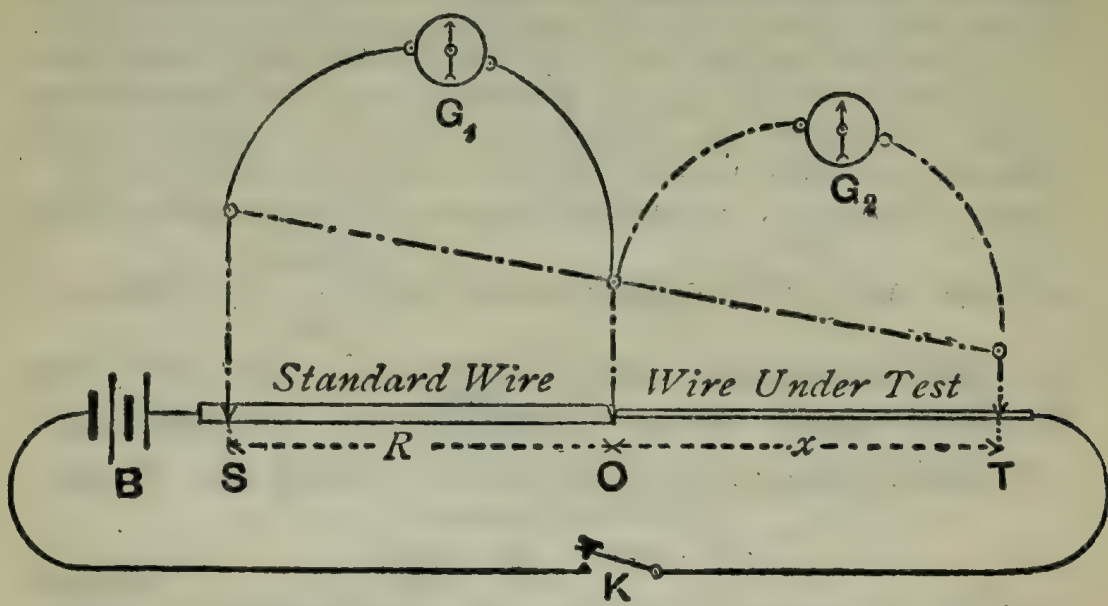


If K be discarded, R will be equal to *x*, when the deflection with R thrown in is equal to that with *x*.

A resistance, *r*, may be added to keep the battery from running down.

Difference of Potential Method for finding the resistance of short lengths of wire, or low resistances (see fig., p. 94). (1.) Join the *standard wire* to the *wire to be tested* by soldering or a mercury cup, or other good connection at O, in circuit with a constant battery, B (such as a few standard Daniells or chloride of silver cells), and a key, K. (2.) Mark off on the standard wire a fixed length, S O, or resistance, R (say 100 inches or 100 centimetres), and note the deflection, d_1, obtained on a mirror galvanometer of very high res. in comparison with wires to be tested, or a quadrant electrometer ; when in the position, G_1. (3.) Switch G_1 quickly into the

position, G_2, by means of an ordinary reversing switch, and obtain a deflection, d_2.



If the wire under test be long enough, slide T along until $d_2 = d_1$. Then $R = x$.

If the length or resistance of O T cannot be altered, and represent say the contact resistance between a dynamo brush and its commutator, or a low resistance armature coil, the contact at S may be shifted until the deflection, $d_1 = d_2$ then $R = x$, R being known.

PERCENTAGE CONDUCTIVITY.—*Wires of same Sectional Area.*—In finding the percentage conductivity of wires of the same sectional area and resistance—*i.e.*, when $d_1 = d_2$ (see last fig.), the ratio of their lengths, S O : O T, is directly as the ratio of their purities or conductivities. Thus, if the standard wire be pure, or = 100,

$$\underset{\text{Length.}}{SO} : \underset{\text{Length.}}{OT} :: 100 : y$$

i.e., y = the percentage conductivity of the wire under test.

Wires of different Sectional Area.—If the sectional area of the wire under test be different from that of the standard wire, the corresponding length of an equal res. of the former must be found by proportion, in order to obtain its conductivity in terms of the standard wire.

Example.—100 inches of pure copper wire, No. 16, in circuit with 55 inches of a No. 18 wire when $d_1 = d_2$; find the percentage conductivity of the No. 18 wire?

Sectional area of the standard No. 16 wire = ·0033 sq. ins.
" " of the No. 18 wire . . = ·0019 "

1st. Find the length of No. 18, which will give the same res. as No. 16, supposing it to be of the same material and purity.

Sq. in. Sq. in. In.
·0033 : ·0019 : : 100 : l
l = 57·57 inches,

i.e., 57·57 inches of No. 18 will have the same resistance as 100 inches of No. 16; but by the test it was found that 55 inches had the same resistance at the same temperature, therefore its conductivity is less.

2nd. The percentage conductivity is found by the proportion

In. In.
57·57 : 55 : : 100 : y
y = 95·5 per cent.

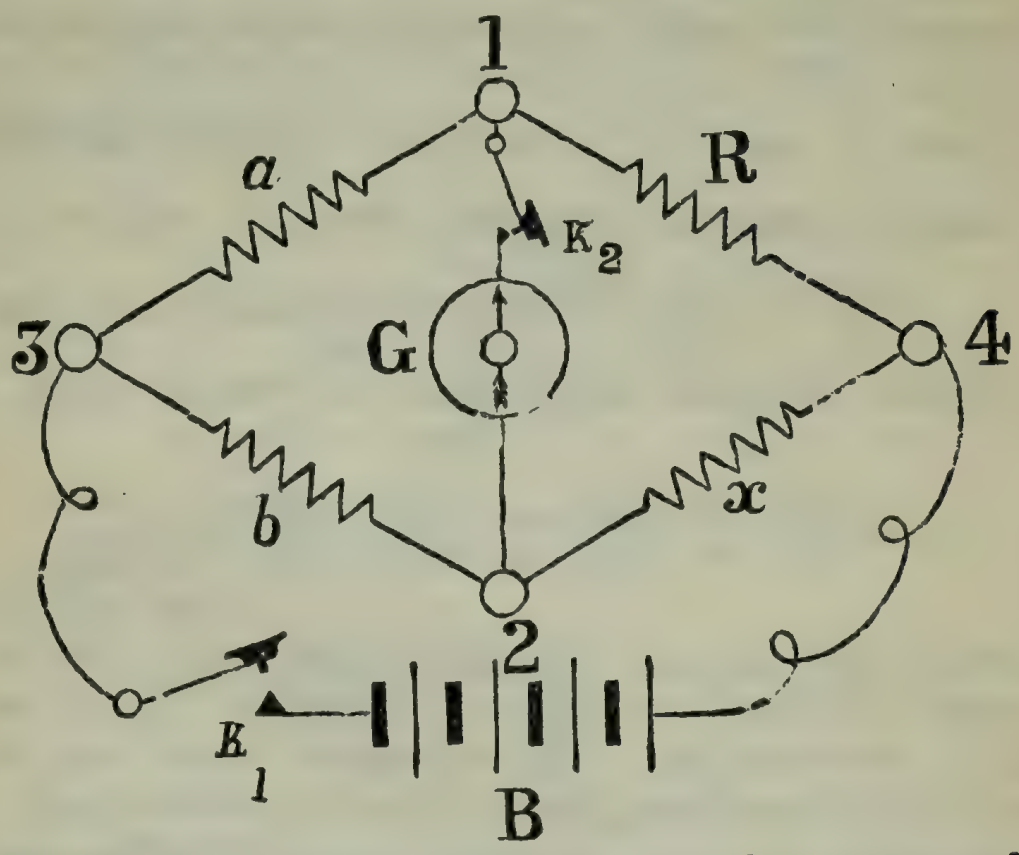
NOTE.—See Index for percentage conductivity formula.

THOMSON'S MHOMETER.—This instrument is designed for obtaining the conductivities or "mhos" $\left(\frac{1}{\text{ohm}}\right)$ of short lengths of wire, or the reciprocal of very low resistances. (See p. 106.)

It consists of a central astatic needle current galvanometer placed in direct circuit with the conductor whose conductivity is to be measured, and two fine German silver or copper wire controlling coils fixed perpendicularly to it. The two ends of these coils are put in metallic connection with two points of the conductor between which the conductivity is to be determined. The resistance of the controlling coils, or an added resistance in series with them is adjusted to make the constant a convenient round number or decimal

The tangents of the deflections of the needle multiplied by constant of instrument give the mhos.

By Wheatstone's Bridge.—Wheatstone's bridge or balance consists of four separate resistances, a, b, R, and x, arranged as shown in the theoretical diagram, with battery, B, galvanometer, G, and keys, K_1, K_2.



x is the unknown resistance to be measured, a and b are two fixed resistances.

R is a variable resistance which is adjusted until no deflection is observed on galvanometer, G, when K_1 and K_2 are depressed.

Then the following ratio exists—

$$a : b :: R : x,$$
$$\text{or } a\,x = b\,R,$$

i.e., the products of the opposite sides of the bridge are always equal to each other,

$$\therefore\ x = R\,\frac{b}{a}.$$

Should the resistances a and b be equal, the value of x is read at once from R; should they, however, bear a certain ratio to each other, such as 1 to 10, 1 to 100, &c., or 10 to 1, 100 to 1, &c., R must be multiplied or divided by that ratio.

When further accuracy is desired than can be obtained by the ratios of a to b at disposal, note the galvanometer deflections to left and right, with the lesser and greater resistances in R respectively, and calculate by proportion the true resistance.

For example, let $a = 1000$ and $b = 10$, and let the true resistance of x lie between 5·11 and 5·12. If with R = 511 we get 6 divisions to left $= d_1$, and with R = 512 we get 12 to right $= d_2$.

Then $(d_1 + d_2) : 1 :: d_1 : y$,

i.e., $(6 + 12) : 1 :: 6 : y = \dot{3}$,

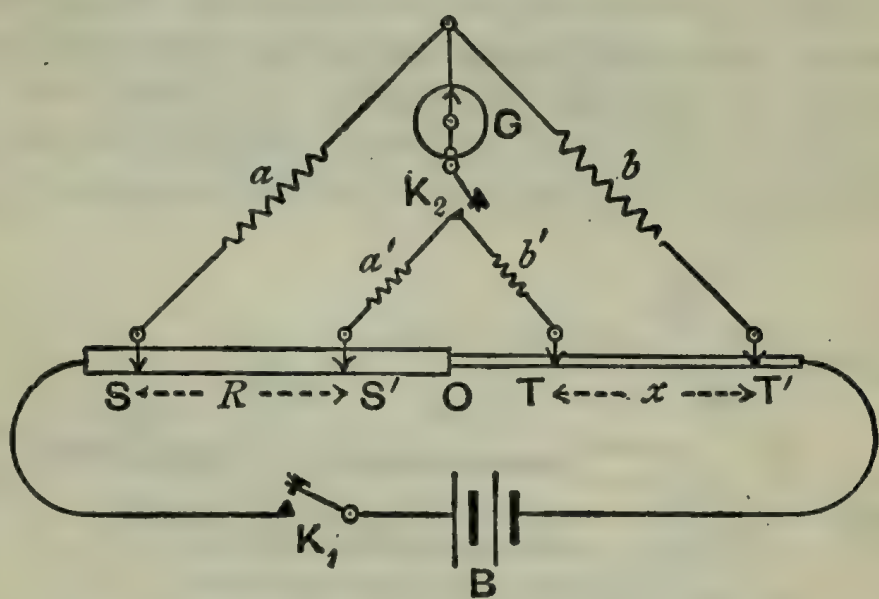
$\therefore x = 5{\cdot}11\dot{3}$.

This method is very often used in practice with $a = b$ instead of using $\frac{b}{a} = \frac{1}{10}$ or $\frac{1}{100}$.

To give the best results, b should be intermediate between $r + x$ and $\frac{Gx}{G + x}$, and R should be intermediate between $G + x$ and $\frac{rx}{r + x}$, where r = res. of battery (see Index for C R tests of Cables).

Thomson's Bridge, for measuring small resistances. The ordinary Wheatstone bridge is unsuitable for measuring very low resistances, because the resistance of the connections, due to imperfect contact or soldering, vitiate the result. Sir William Thomson's modification of

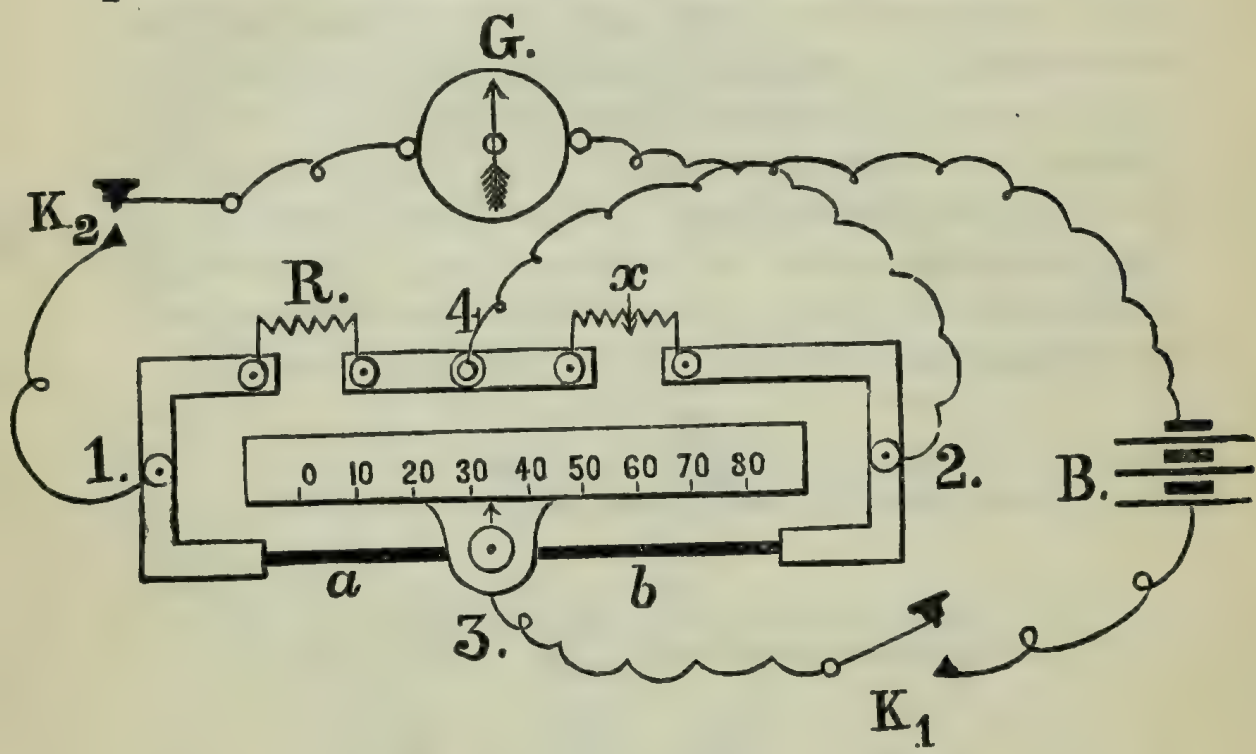
the bridge is designed to avoid this fault; and it is useful in determining the specific conductivity of metals, as compared with a standard (*e.g.*, pure copper), especially when the metal is not in the form of a long wire, or for measuring the resistance between the brushes and commutator of a dynamo, or the sections of a low resistance armature.



In the figure a, b; a', b', are resistances so great that the resistances of their contacts with the *standard wire* and *wire under test* at S, S′, T, T′, may be neglected. These wires are soldered together, and the current from a constant battery, B, sent through them by closing K_1. The high resistance galvanometer, G, is thrown in by the key, K_2. The following relation must hold $\left.\begin{matrix} a & : b \\ a' & : b' \end{matrix}\right\} :: R : x$, and if there is no resistance at the contact, O, between the standard wire and wire under test, when there is no deflection on G, we have

$$a : b :: R : x, \text{ or } x = R\frac{b}{a}.$$

SLIDE WIRE OR METRE BRIDGE. — For measuring the resistance of short lengths of wire. The letters and numbers in this and the following practical forms of bridge correspond to those in the theoretical bridge, fig. p. 96.



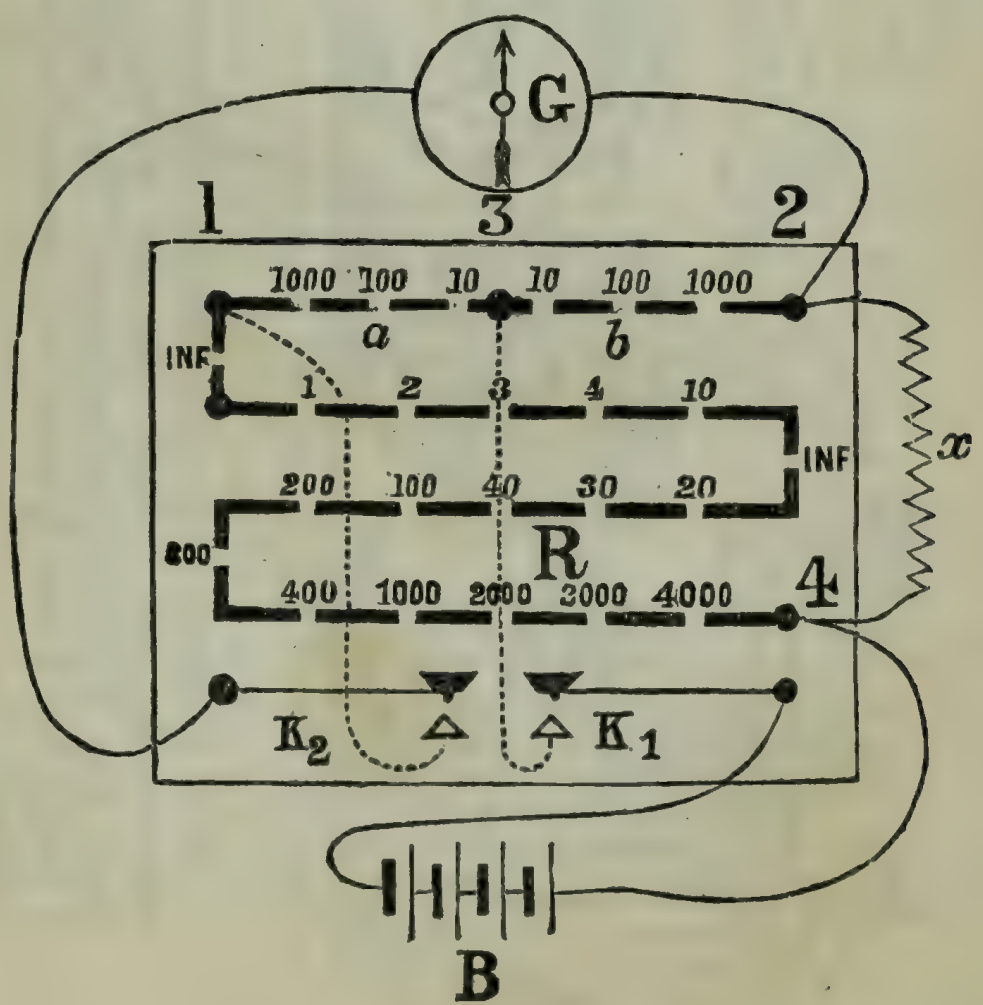
The resistances, *a*, *b*, consist of a slide wire of platinum-iridium, 1 metre long and about 1·5 mm. in diameter, stretched parallel to a metre scale graduated in millimetres, and with its ends opposite the divisions marked 0 and 1,000. A sliding contact, 3, is moved up or down the wire until a balance is obtained.

Although great accuracy is not obtainable by this kind of bridge, as its working depends upon the assumption that the wire, *a b*, is of uniform resistance throughout, it is nevertheless a very useful form for the workshop, and is generally used in connection with a horizontal needle or tangent galvanometer, G. of low resistance, and a Daniell's or De la Rue's chloride of silver battery, B.

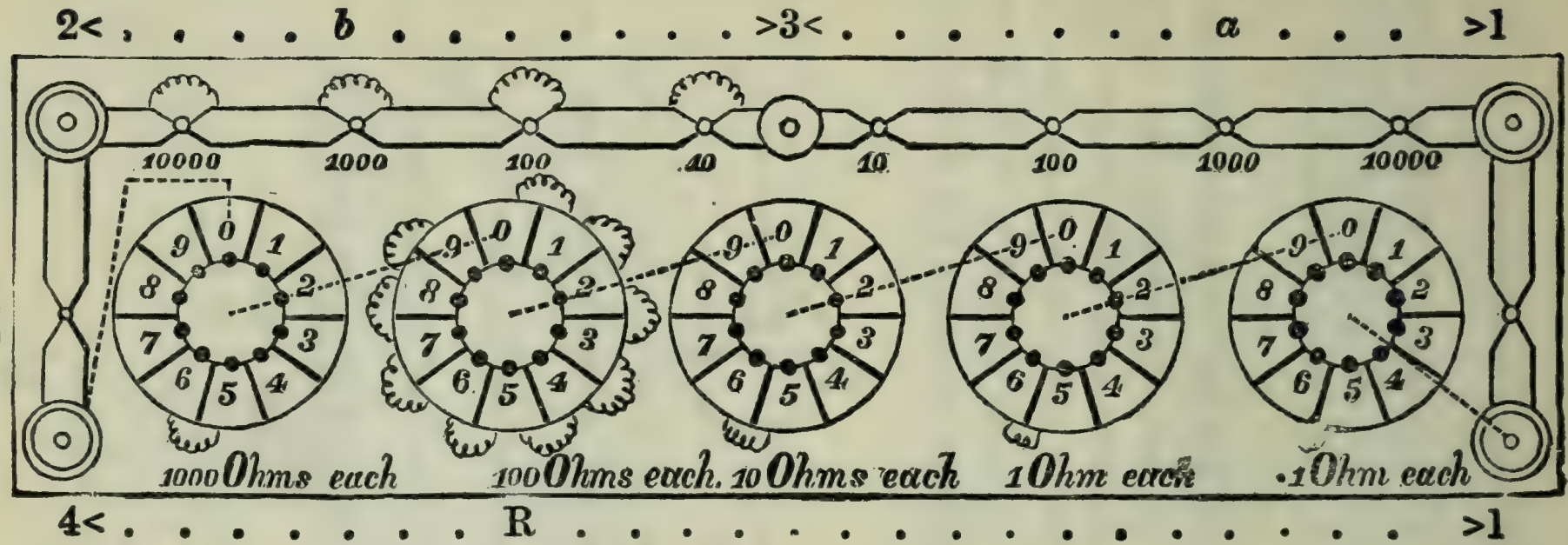
The standard resistance, R, should be nearly equal to x, so that, in getting a balance, the slide contact, 3, may be about the middle of the wire.

It is better to cut out the galvanometer by a short circuit key than by opening the circuit.

Combined Bridge and Resistance Box.—*Post-Office Pattern.*—In this form the resistances are brought into circuit by taking out the plugs from the holes between the contact bars.

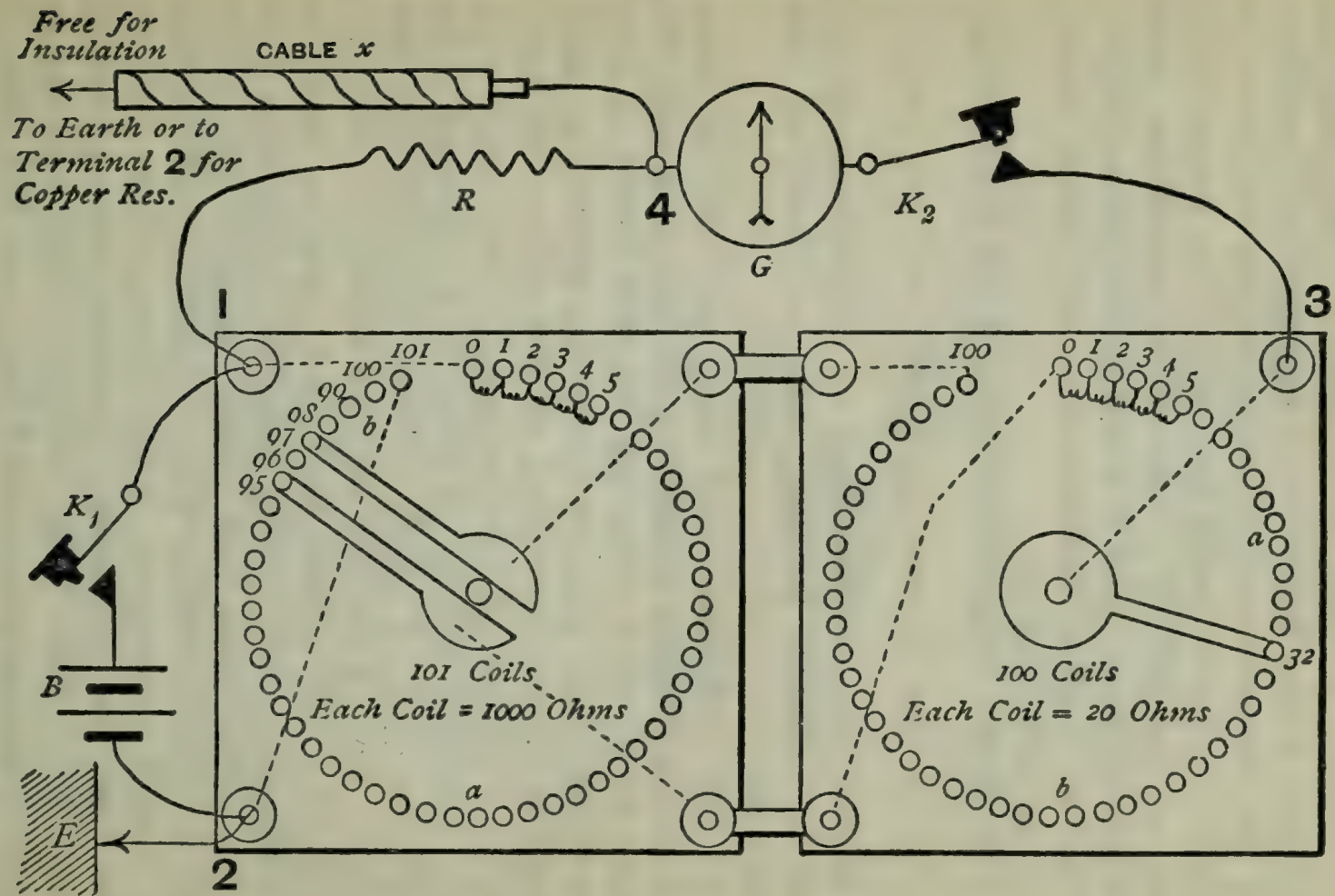


Dial Pattern.



Dial Pattern.—In this form, the resistances are brought into circuit by introducing the plugs into the holes. It is therefore easier to read from than the Post-Office pattern. The infinite resistance plug (INF.) between 2 and 4, or 1 and 1, must be removed when taking resistance by the Bridge method.

Thomson and Varley's Slides.



Thomson and Varley's Slide Coils.—Plan of internal and external connections, joined up as an ordinary bridge.

The fig., p. 102, is a plan of Thomson and Varley's slide coils, with connections for testing the resistance of wires or cables on closed or on earth circuit, and fig., p. 104, a geometrical plan of the fall of potential in the slides, with the connections used in testing submarine cables, either for copper resistance or insulation during or after submersion.

The slides replace two arms of the Wheatstone bridge (a and b, see fig., p. 96), and the ratio $\frac{a}{b}$ is varied, not by inserting or taking out plugs, but by simply turning one or both of the handles.

In the left-hand box (fig., p. 102) we have the slides proper, consisting of 101 coils of 1,000 ohms each, or a total of 101,000 ohms, and in the right-hand box we have the vernier or subdividing slide, consisting of 100 coils of 20 ohms each, or a total of 2,000 ohms. The double contact pointer, which is free to be moved from end to end of slide (from 0 to 99 on one pointer and 2 to 101 on the other, or over 99 coils of 1,000 ohms each, *i.e.*, over a total of 99,000 ohms on either pointer), embraces two coils, 2,000 ohms, but being attached to ends 0 and 100 of the vernier slide, it thereby introduces an equal resistance, 2,000 ohms, thus making the absolute resistance between the pointers equal to 1,000 ohms, or the total resistance between the points 1 and 2 (figs., pp. 102–104) of 100,000 ohms; for let

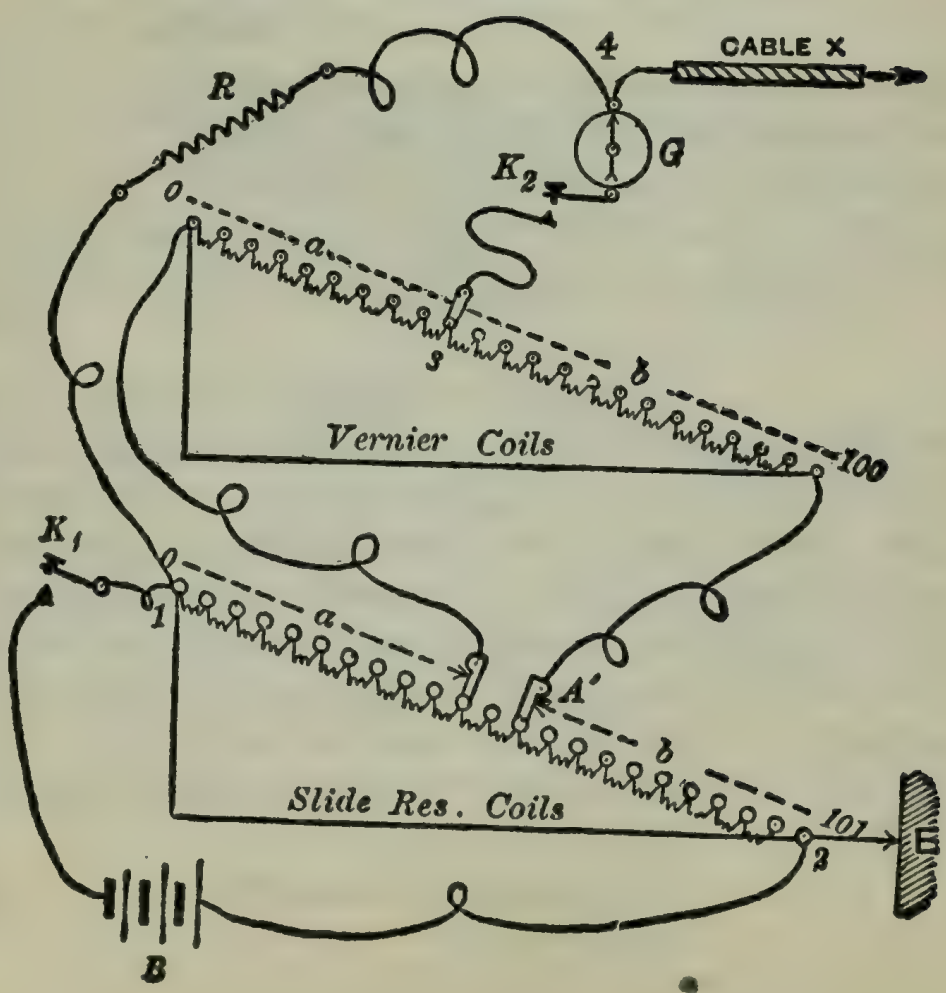
G = resistance between the two pointers in left hand slides = 2,000 ohms,

S = resistance between 0 and 100, on vernier slide = 2,000 ohms; then, by shunt formula the joint resistance between two contact pointers,

$$= \frac{GS}{G + S} = \frac{2{,}000 \times 2{,}000}{2{,}000 + 2{,}000} = 1{,}000 \text{ ohms.}$$

Part of the current from the battery therefore flows on short circuit through this 100,000 ohms resistance, and the remaining part through the resistance, R, and cable, x.

Plan of Slide Coils, with Connection for Copper Resistance and Insulation Test.—The same letters and numbers are used here as in fig., p. 102.



TESTING WITH SLIDES.—In taking a test of a cable, either for copper resistance or insulation, all that has to be done is to introduce a suitable resistance, R, and move the slide handles until no deflection is observed on the galvanometer. When earth-currents are present, balance to earth current zero. Then read the number on side of slides from zero marked a (figs., pp. 102–104), and work out the following equation:—

If R = resistance introduced in position R

a = reading on slides, *i.e.*, from 0 to first pointer on left-hand or double pointer slide, plus 0 to single pointer on right-hand slide; see example, p. 106.

$b = 10{,}000 - a$.

x = resistance of cable to be found.

By rule for Wheatstone bridge (see p. 96) we have

$$a : b :: \mathrm{R} : x,$$

$$a : (10{,}000 - a) :: \mathrm{R} : x,$$

$$a x = (10{,}000 - a)\,\mathrm{R},$$

$$\therefore\ x = \left(\frac{10{,}000 - a}{a}\right)\mathrm{R} = \left(\frac{10{,}000}{a} - 1\right)\mathrm{R}.$$

Look out the reciprocal of the reading (a) in the tables, multiply it by 10,000, subtract 1 and multiply by R to get x. For copper resistance tests, R may conveniently be taken as the nearest multiple of 10 to the resistance of the cable or wire under test, and for insulation 1 megohm answers very well.

Example. — The reading (a) on the slides (pp. 102-105) is 9,532,

$$\therefore b = (10{,}000 - a) = (10{,}000 - 9{,}532) = 468.$$

If R = 1,000 ohms, then by the formula

$$x = \left(\frac{10{,}000}{a} - 1\right)\mathrm{R} = \left(\frac{10{,}000}{9{,}532} - 1\right) 1{,}000$$
$$= 49{\cdot}09 \text{ ohms.}$$

Or by referring to tables of reciprocals, we find $\frac{1}{9{,}532} = {\cdot}000104909$,

$$\therefore {\cdot}000104909 \times 10{,}000 = 1{\cdot}04909;$$
$$(1{\cdot}04909 - 1)\ 1{,}000 = 49{\cdot}09.$$

The tests and calculations for resistances by the slides are thus very easily, accurately, and quickly made.

These slides are much used on cable expeditions.

Ayrton and Perry's Ohmmeter gives res. by direct reading. It consists of two coils at right angles to each other, one of thick wire connected in circuit with, and one of fine wire connected in shunt, to the resistance to be measured. The coils act on a soft iron needle, which indicates the resistance in ohms.

RESISTANCE OF GALVANOMETERS.

ORDINARY METHOD.—When a second galvanometer is at hand, proceed by the Wheatstone bridge test, see p. 96, inserting the galvanometer whose resistance is required into position of x.

This is by far the most reliable method. Note the temperature at the time of taking the galvanometer resistance, which will save the trouble of taking it again at that temperature. If the needle of the galvanometer to be tested is delicately suspended, it should be removed during the test, or let down and fixed; care being taken not to reverse its polarity by the current.

HALF DEFLECTION METHOD.—Connect the galvanometer to be measured, in circuit with a resistance, R, and battery, as in fig., p. 109. Note the deflection, d. Next increase R to R_1, so that the new deflection $d_1 = \frac{d}{2}$. Then,

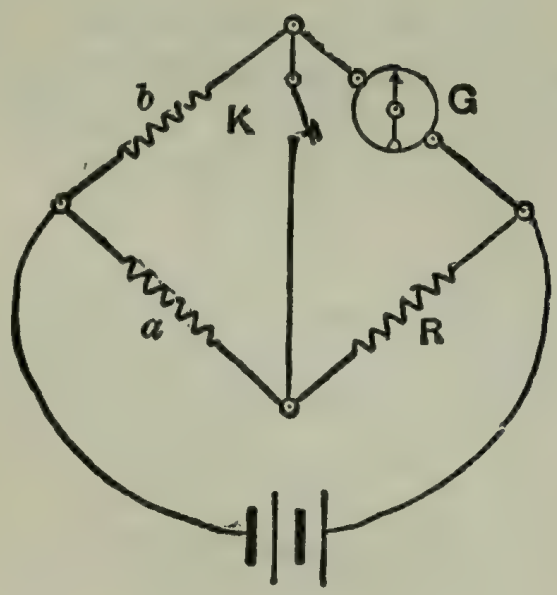
$$G = R_1 - 2R.$$

The best condition is to make R a fraction of G; with a tangent galvanometer, d and d_1 are the tangents of the deflections. These deflections should be as nearly as possible 55° and $35\frac{1}{2}°$. If the value of deflection is correct to x per cent., then G may be correct to $2x$ per cent.

EQUAL DEFLECTION METHOD.—Connect the galvanometer, having a shunt, s, between its terminals, in circuit with a resistance, R, and a battery of very low resistance, see fig., p. 109. Note the deflection, d. Next remove the shunt, and increase R to R_1, so that the deflection, d, is reproduced. Then,

$$G = s\frac{R_1 - R}{R}.$$

THOMSON'S METHOD.—Connect the galvanometer in a Wheatstone's balance of resistances, a, b, R, with a key, K, as shown in the figure. Adjust R until the deflection on the galvanometer is the same, whether K be closed or open.



Then $$G = R\,\frac{b}{a}.$$

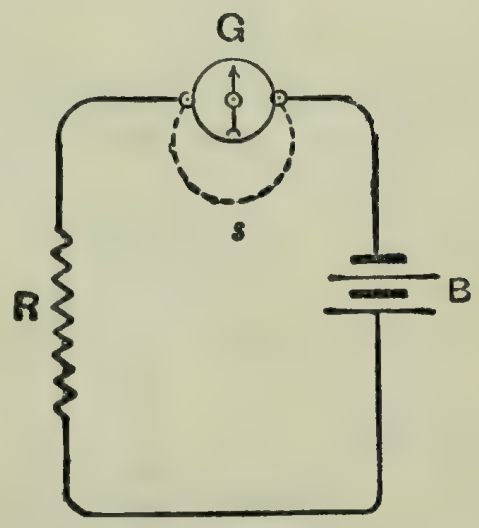
This test is independent of battery resistance. The battery should connect the junction of the two highest with that of the two lowest resistances. If the deflection is accurate to x per cent., the value of G will be the same.

By a Shunt.—Measure the res., s, of the $\frac{1}{n}$th shunt of the galvanometer by Wheatstone's bridge, then $G = (n \times s) - s$. (See p. 68.)

RESISTANCE OF BATTERIES.

By Reduced Deflection. — Connect the battery whose resistance, B, is to be measured, in circuit with a galvanometer, G, and a resistance, R, as in the figure. Note the deflection, d. Then change R to a greater resistance, R_1, and note the smaller deflection, d_1; then if the deflections are directly proportional to the currents,

$$B = \frac{R_1 d_1 - R d}{d - d_1} - G.$$



In this, as in similar cases, it is well for the reduced deflection to be about ½ of the full deflection.

Half Deflection Methods.—First,—When R_1 is made such that $d_1 = \frac{d}{2}$, then if the deflections are directly proportional to the currents

$$B = R_1 - (2R + G).$$

Rule.—Double the smaller resistance, add the resistance of the galvanometer, and deduct the sum from the greater resistance.

The best conditions for the test are when R + G is a fraction of B. This requires a galvanometer of low resistance. If the galvanometer deflections are accurate to x per cent., the value of r will be accurate to 2 x per cent.—*Kempe.*

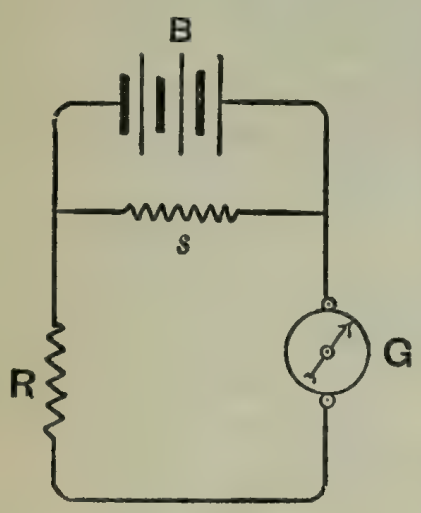
To lessen polarisation, d_1 may be taken first.

Second,—Shunt the galvanometer with a short thick wire, s, so that the resistance, $\frac{G\,s}{G+s}$, may be neglected; obtain a deflection, d, with only the galvanometer and battery in circuit, then introduce a resistance, R, until d is halved, when

$$B = R$$

This is the simplest and readiest method.

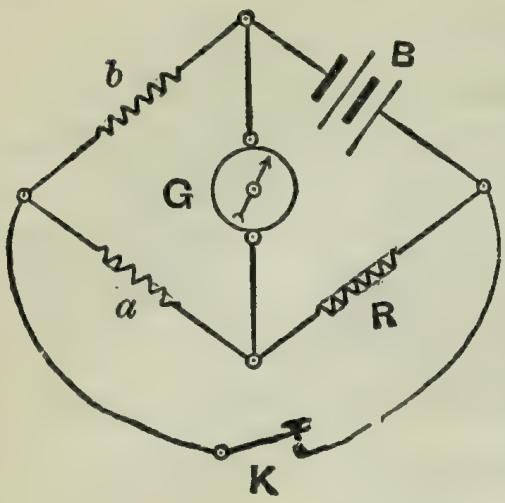
THOMSON'S METHOD.—Connect the battery having a shunt, s, between its poles, in circuit with a galvanometer, G, and resistance, R. Note the deflection, d. Next remove the shunt, and increase R until the deflection, d, is reproduced. If R_1 be the new resistance, then



$$B = s \cdot \frac{R_1 - R}{R + G}.$$

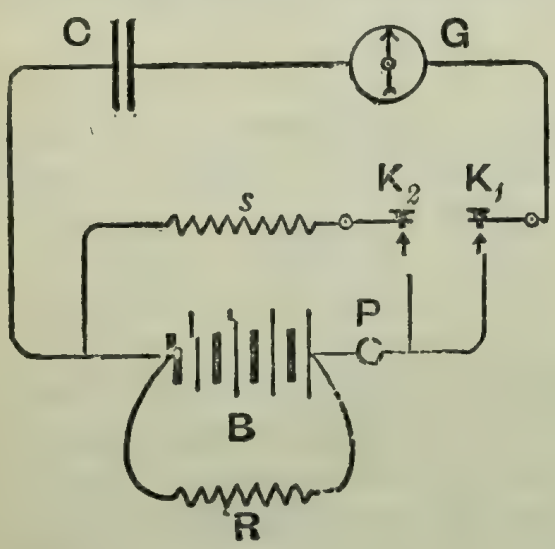
MANCE'S METHOD.—Connect the battery in one side of a Wheatstone balance of resistances, a, b, and R (see fig., p. 111), with a key, K, as shown. Adjust R until the deflection on the galvanometer remains the same, whether K is closed or open.

Then $$B = R\frac{b}{a}.$$



The E.M.F. of the battery need only be constant whilst the key is worked. The galvanometer should connect the junction of the two highest, with that of the two lowest resistances. If the deflection is accurate to, x, per cent., the value of, B, will be the same.

Resistance of a Battery Working.—In practice, it is useful to know the resistance of a battery, when working through a given resistance, say, an electric light circuit. Connect the battery, B, through the resistance, or its equivalent, R, and also in derived circuit, through a Thomson galvanometer, G, condenser, C, from $\frac{1}{3}$ to 1 microfarad, and a key, K_1. Join a shunt, s, across its poles by the key, K_2. Close K_1, and note deflection, d_1. Still keeping, K_1, down, close K_2, and note reverse deflection, d_2. Then the battery resistance,



$$B = s \frac{d_2}{d_1 - d_2 - \frac{d_2 s}{R}}$$

When R is great, the term $\frac{d_2 s}{R}$ is negligible; when R is absent it disappears, and B is the resistance of the battery idle. It is best if $d_2 = \frac{d_1}{2}$; but, practically, d_2 needonly differ largely from d_1.

With a plug piece inserted at P:—Close K_1, and when the needle returns to zero, close K_2. Note the deflection, D_1. Keeping K_2 down, open K_1 and remove the plug, P. When the needle is again at zero, strike K_1. Note the discharge, D_2. Then

$$B = s\frac{D_1}{D_2}.$$

Without K_1, the discharge, D_2, is got on removing P.

Another method, useful when R is varied. Insert a key, K_3, between R and one pole of the battery, and plug in P. Close K_3 till the current is steady, then open K_3 and close K_1, noting the deflection, d_1. Open K_1 and close K_3, and, when the galvanometer comes to zero, open K_3, then close K_2 and K_1 in quick succession, noting the deflection, d_2. Then

$$B = s\frac{d_1 - d_2}{d_2}.$$

It is best that s be not less than B or greater than 2B.

—*C. H. Pownall.*

Another method, Applicable also to Dynamos—

1. Observe by a voltmeter the difference of potential between terminals when on open circuit; let this be E_1.

2. Do the same when working through a known resistance; let this be E_2. In the case of a battery this should be noted quickly before polarisation sets in. Also note the current, C, by an ampere meter. Then the resistance of battery or dynamo will be, $\frac{E_1 - E_2}{C}$. For, when a current is flowing, part of the total E.M.F. is taken up in sending current through the known resistance and part through the battery or dynamo, but only that part, E_2, which is acting on the external circuit, can be directly measured.

$E_1 - E_2$ is therefore the E.M.F. used in overcoming the internal resistance.

$$\therefore\ C = \frac{E_1 - E_2}{B}, \text{ or } B = \frac{E_1 - E_2}{C}.$$

—*Edgar Smart.*

Large Batteries and Accumulators may be split in two, and the halves opposed to each other, then tested in Wheatstone's balance.

An extra cell or accumulator may be left on one part to give sufficient current to test the

whole by the discharge or other methods.—*Kempe.*

Polarisation of Batteries.—To see how much a battery runs down in working on short circuit, or otherwise, connect it through a galvanometer and condenser, as in fig. p. 111, and short circuit or shunt its poles, using the keys, K_1, K_2. The discharge by K_1, on opening K_2, will show the state of the E.M.F.

Again, connect the cell to be tested in circuit with a galvanometer, and a standard cell opposed to it. Short circuit the cell, and at intervals remove the short circuit to note the deflection, if any.

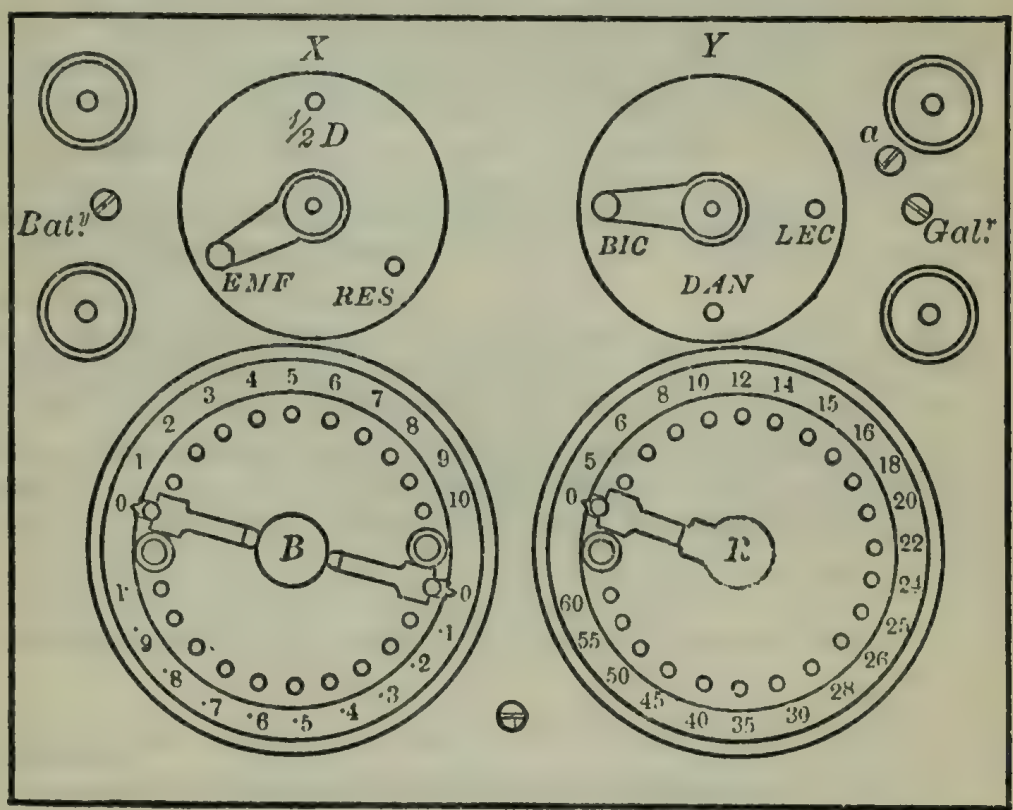
TESTING BATTERIES.

Latest Instructions by G.P.O.

Use of the "Direct-reading" Battery Testing Instrument.

1. In order to simplify the method of estimating the electro-motive force and resistance of batteries, and lessen the time necessary for the tests, a new instrument has been devised, which obviates the necessity for any calculation, or any reference to Tables.

2. The following sketch and instructions explain the mode of using the apparatus :—



Method of taking the "Constant."

3. The "Constant" of the Galvanometer should be taken in the usual manner, by joining the Standard cell direct to the Tangent Galvanometer * and removing the Galvanometer plugs.

* The skew scale is always used by the G.P.O. with their Tangent Galvanometer. See Kempe on "Electrical Testing," p. 19, 4th edition.

The standard deflection should be 80 divisions on the *outer* scale if the resistance of the Standard cell does not exceed 4 ohms (see paragraph 12); if it is more than 4 ohms the deflection should be just under 80 to allow for the extra resistance.

4. Care should be taken that the Galvanometer needle comes to the Zero of the outer tangent scale, when a current s *not* flowing in the coils, both *with* and *without* the controlling magnet.

To ascertain the "Percentage of Fall of Electro-motive Force."

5. The Standard cell being removed, the Galvanometer is joined to the right-hand terminals of the "Battery Testing Instrument," the arm of the Rheostat, R, is placed at the figure indicating the number of cells to be tested, and the switch, Y, is placed at "BIC," "LEC," or "DAN," according to the description of battery which is to be tested.

The right hand Galvanometer-plug should be inserted so as to take the 750ω resistance-coil out of circuit.

6. The battery under test being connected to the left-hand terminals, a deflection of 100 divisions on the *outer* scale of the Galvanometer will be obtained if the battery is in perfect condition. Any less deflection will indicate a fall of force, the percentage amount of which is ascertained direct by reference to the *inner* scale, 90 on the outer scale being marked 10 on the inner, 85 on the outer scale, 15 on the inner, and so on.

7. The maximum percentage fall which is allowed is, for Leclanchés 25, for Bichromates 15, and for Daniells 10.

To Estimate the "Electro-motive Force in Volts."

8. The "percentage of fall" is all the information that is necessary for the official "Battery Testing Report," but if the force in "volts" required *for any special purpose*, it can be ascertained by multiplying the theoretically perfect force *in "volts,"* by the number of tangents indicated on the *outer* scale, and dividing the result by 100.

For example, the electromotive forces of a Bichromate, a Leclanché, and a Daniell battery, each giving 95 divisions on the outer scale (or a 5 per cent. fall as shown on the inner scale), would be calculated thus:—

Bichromate	= 2·14 × ·95 = 2·033	volts.
Leclanché	= 1·60 × ·95 = 1·520	"
Daniell	= 1·07 × ·95 = 1·017	"

To Test for "Resistance per Cell."

9. The electromotive-force deflection having been noted, the switch, Y, and rheostat, R, are left as in the E.M.F. test, and the principal arm of the rheostat, B, is placed at its highest point (10ω).

The switch, X, is then turned to "Res," and the resistance in, B, is lowered, until the deflection on the Galvanometer shows *a tendency* to fall below the original electromotive force deflection.

At this point the rheostat, B, will indicate the "resistance per cell."

10. The switch, X, may then be turned to "E.M.F." to determine whether polarisation has produced any change in the original deflection, and if this is found to be the case, a new observation should be made, but if the test is rapidly effected, polarisation will not interfere.

Exceptional Tests of Batteries of higher Resistance than that allowed by the Department for Circuit Working.

11. For batteries having a higher resistance than 10ω per cell the following method should be used—

The switch, X, being placed at "½ D" instead of at "Res," rheostat, B, should be altered until the electromotive-force deflection on the outer scale is halved. The "resistance per cell" as indicated on rheostat, B, should then be multiplied by a coefficient, if the number of cells is less than 60.

The coefficients are given in the following table:—

No. of Cells.	Co-efficient.	No. of Cells.	Co-efficient.	No. of Cells.	Co-efficient
5	12	14	4·3	25	2·4
6	10	15	4	30	2
8	7·5	16	3·8	35	1·7
10	6	18	3·4	40	1·5
12	5	20	3	50	1·2

This method is more sensitive for batteries of any resistance *of fewer than* 20 *cells each*, but is more likely to be interfered with by polarisation.

Method of checking the Standard Cell Resistance.

12. When the Standard cell is connected to the Galvanometer to adjust the "Constant" deflection, the resistance of the cell can be checked thus:—

Leave the connections as for the "Constant," and join two additional wires from the terminals of the battery to the battery-terminals of the "Testing Instrument." Put the "X" switch in the position "½ D," place the arm of the Rheostat "R" at Zero, and the arms of Rheostat "B" at ·1ω.

The deflection obtained should not be *less* than 40; if less than 40 the resistance of the cell exceeds 6ω, and should be reduced.

If necessary, the exact resistance of the cell may be ascertained as follows:—

Multiply the difference between the Standard deflection (80) and the second deflection (d_2) by 6, and divide the result by the second deflection, that is to say—

$$\text{Standard Cell, R} = \frac{(80 - d_2)\,6}{d_2}$$

To ascertain Resistance without previously estimating Electro-motive Force.

13. When it is desired to find the "resistance per cell" of any battery without reference to its electromotive force,

put R to the number of cells, and arrange switch, Y, to suit the description of battery to be tested, then proceed as usual. In this case the Galvanometer need not be adjusted to any constant, provided that the plugs of the Galvanometer are in such a position that the total resistance of the latter is 320ω.

Theory of the Tests.

The theory of the instrument may be explained thus:—

Test for Electro-motive Force.

14. In order to get the same deflection with any number of cells, the resistance must be increased in direct proportion to the number tested.

This is effected by the Rheostat, R, by means of which a resistance of 428ω is inserted for *each* cell under test; this figure being selected as suitable to the Post-Office Tangent Galvanometer.

(With the standard cell, however, a resistance of 750ω in the testing instrument, and 320ω in the Galvanometer is in circuit, exclusive of the resistance in the cell itself.)

15. As Bichromate and Leclanché, under these circumstances, would give a greater deflection than Daniell cells, a switch, Y, is added, which shunts the Galvanometer, and adds compensating resistances when turned to "Bic" or "Lec."

The electromotive force is then determined as explained in the practical instructions.

Test for Resistance.

16. When a battery is shunted with a wire of a certain resistance, the electromotive force *at the battery terminals* is reduced, in the proportion of the original total resistance of the battery to the *joint* resistance of the battery and shunt.

The available external electromotive force being thus reduced, the obtainable deflection through, R, would be correspondingly decreased, but if it were possible to lower R in the same proportion the deflection would be unaltered.

17. Now, as stated above, R, for n cells, is always n times 428ω; 428 may therefore be regarded as the unit resistance, and if a shunt, S, of y times 428ω is placed across the resistance, R, the *joint* resistance $\frac{RS}{R+S}$ is less than the

original resistance, R, in exactly the same ratio as the new "E.M.F." is less than the original E.M.F., when y times the resistance of the battery is shunting it.

18. The shunt "S" is of fixed resistance, and should (theoretically) be equal to the highest resistance which R can be made, viz., that in use when 60 cells are being tested. "S" should thus be equal to $60 \times 428\omega$ if it were not essential to make the corrections referred to in paragraphs 24 and 25.

19. To have an unaltered deflection, therefore, when the S shunt is applied, and when 60 cells are being tested, the battery must be shunted by a resistance equal to itself, which is of course 60 times that of one cell.

Now, if on the rheostat, B, 60ω were marked as 1ω, the indicated result would be the mean resistance of each cell.

20. If 5 cells were being tested, R would be (as already mentioned) $5 \times 428\omega$, and S being equal to 60×428, S is therefore $12 \times$ R. The deflection in this case would be unaltered when the battery shunt, B, = battery resistance $\times$ 12.

Say battery $= 10\omega$ total, or 2ω per cell.

B would be $10 \times 12 = 120\omega$, and if 60ω were marked as 1ω, then a *resistance per cell* of 2ω would be indicated, as $\frac{120}{60} = 2$.

S might, however, be any muliple of R, if B were made to bear a similar proportion to the battery resistance, the indicated value of the B coils being altered accordingly.

21. As 60 is the highest number of cells in use in the Post-Office Service in one set, this number has been selected.

Resistance Test by Half Deflection.

22. When the "$\frac{1}{2}$ D" position of the switch, X, is used, the shunt, S, is not connected, and the battery shunt, B, is, of course, made equal to the total battery resistance; in this case the indicated result per cell must be multiplied by a coefficient, which represents the fraction of 60 cells which are under test; thus 5 cell results should be multiplied by 12, and 20 cell results by 3.

Automatic Correction for Departure from Theoretical Accuracy.

23. The theoretical values for "S" and B are only applicable when the battery resistance is inappreciable in comparison with the external resistance, and when the Galvanometer is either of very low resistance, or double-

wound, so as to admit of one half of the coils being placed in circuit with B, and the other half in the shunt "S."

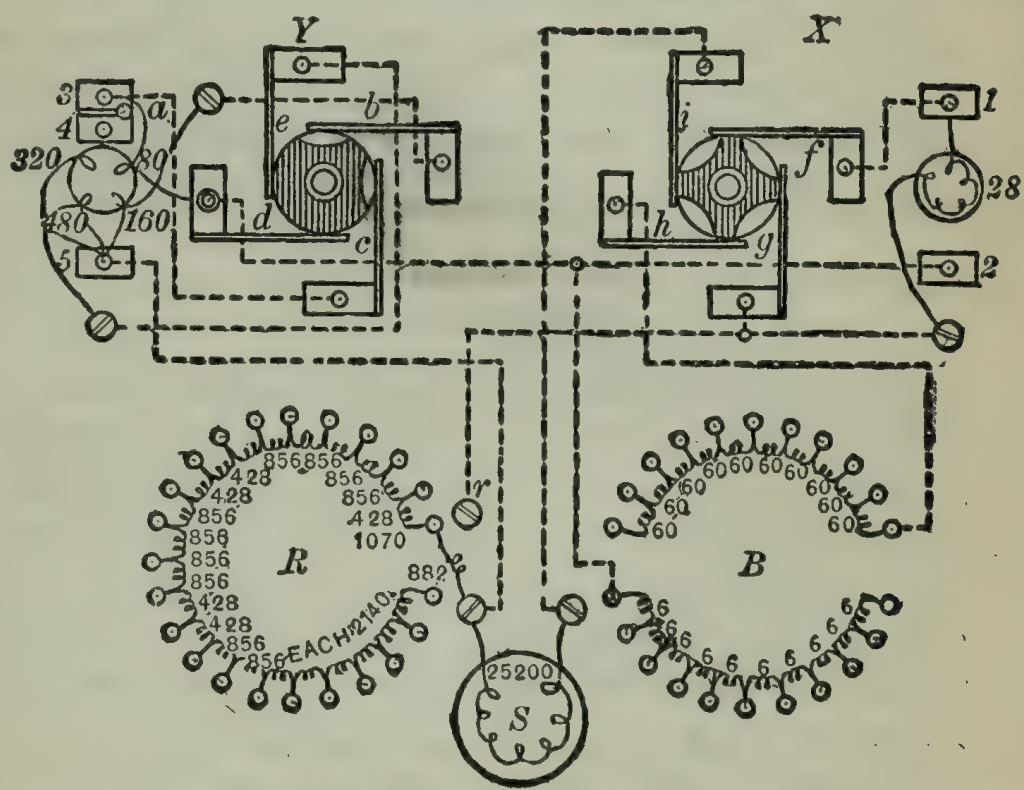
24. The use of a Galvanometer which has a resistance of 320ω, and which is outside of the shunt "S," makes it necessary to compensate for the inaccuracies so introduced, by making "S" = 25,200ω instead of 60 × 428ω, and shunting the Galvanometer by a permanent shunt (contained in the Battery Testing Instrument), so as to reduce its resistance to 160ω.

25. As a further compensation, the switch, X, when turned to "Res," cuts out a resistance of 28ω from the "R" coils.

Connections of the Instrument.

26. Figure below shows the connections of the instrument (as seen from beneath), the switch, X, being in the "E.M.F." position, and the Y switch at "Bic."

In this position of the "X" switch, the springs, *f*, *g*, *h*, *i*, are disconnected, and the springs, *b* and *c*, of the switch "Y" are connected, the course of the current being from



the battery terminal (1) through the 28ω coil to *r*, thence viâ the arm of the rheostat "R" and its coils to the Galvanometer terminal (5). Three paths are available from this point, one viâ the Galvanometer, the second viâ the 320ω coil, and the third viâ the 160ω coil and the springs

"*b*" "*c*," all three paths terminating in the Galvonometer terminal (3),* and thence through the 80ω coil back to the battery viâ the battery terminal (2), the joint resistance of the paths offered to the current, in any position of the "Y" switch, being invariably = 160ω.

In the position just described, the joint resistance of the three paths,—Galvanometer 320ω, coils 320ω, and 160ω,—is 80ω, which, added to the 80ω coil between *a* and *d* = 160ω.

The X switch has three positions, the "E.M.F.," which disconnects all the springs, 'RES" which connects all the springs, and "½ D" which connects *f* and *h*, but leaves *g* and *i* disconnected.

The shunt coil, "S," it will be evident, is brought into use in only one position of the "X" switch, namely, when at "RES.'

The "Y" switch has three positions:—

"BIC" which connects *b* and *c*, leaving the others disconnected;

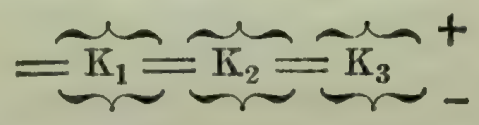
"DAN" which connects *c* and *d*, leaving *b* and *c* disconnected; and

"LEC" which connects *d* and *e*, leaving *b* and *c* "cut." (See also p. 127.)

CAPACITY.

Condensers are Leyden jars of large surface in a small bulk. Muirhead's consist of tin-foil sheets, separated by paraffined paper when used for signalling, and mica plates when used for standards. Alternate foils are connected to form the two poles of the condenser. They can be joined up, like voltaic batteries, in "parallel" or in "series."

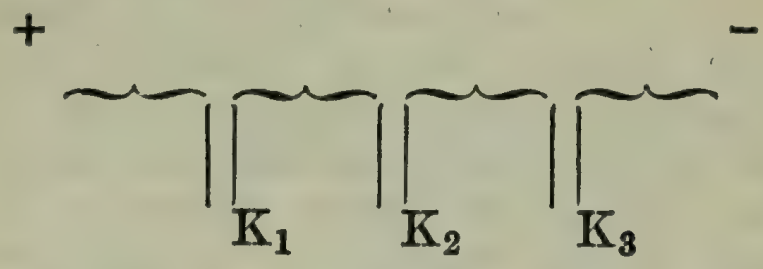
Condensers in parallel.—Like poles, are connected together as in the quantity arrangement of batteries. The joint capacity of the set is equal to the sum of the several capacities. Let K_1, K_2, K_3, be the several capacities, as in figure



Then the total capacity, $K, = K_1 + K_2 + K_3$.

* The block 4 is permanently connected by a screw to block 3. This screw is removed only when it is required to test the instrument in the factory.

Condensers in series.—Unlike poles, are connected together as in the "series" arrangement of batteries, or Leyden jars in "cascade." The joint capacity of the set is the reciprocal of the sum of the reciprocals of the several capacities. Thus, in the figure,



$$K = \frac{1}{\frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3} + \ldots}$$

By combining these two methods, many different capacities can be obtained with a few condensers. Thus two condensers, K_1 and K_2, give four capacities, viz, K_1, K_2, $K_1 + K_2$, and $\frac{K_1 K_2}{K_1 + K_2}$.

Muirhead's Artificial Line, for duplex and quadruplex telegraphy, is an "inductive-resistance" formed by cutting up the alternate plates of a signalling condenser into a strip of foil, doubled on itself like a grid. This ribbon is the artificial circuit, and corresponds in resistance to the cable conductor. The plain sheets of foil represent the earth, and are insulated from the ribbon by the paraffined paper, which corresponds to the insulator of the cable. The resistance, capacity, and insulation of the artificial line are made up equivalent to those of the real cable, especially at the beginning of the line.

MEASURING CAPACITY.

By Direct Discharge.—Charge a standard condenser of known capacity, K_1, by a battery, and discharge it through an astatic or ballistic mirror galvanometer. Note the deflection or swing of the needle, d_1. Next charge the condenser to be measured, K_2, by the same battery; discharge it through the galvanometer, and note the deflection, d_2. Then

$$K_1 : K_2 :: d_1 : d_2, \text{ or } K_2 = K_1 \frac{d_2}{d_1}$$

If $\frac{K_1}{d_1}$ is made a submultiple of 10, d_2 gives the capacity at once.

Thomson's Method.—This method is now almost universally adopted in comparing the capacity of condensers, or cables with condensers, both in the factory and at cable stations.

Taking the Test.

1. Close key 1, then the poles of a well insulated battery, B, of from 1 to 10 Daniell or chloride of silver cells, are joined together through two resistances, R_1 and R_2, to earth.

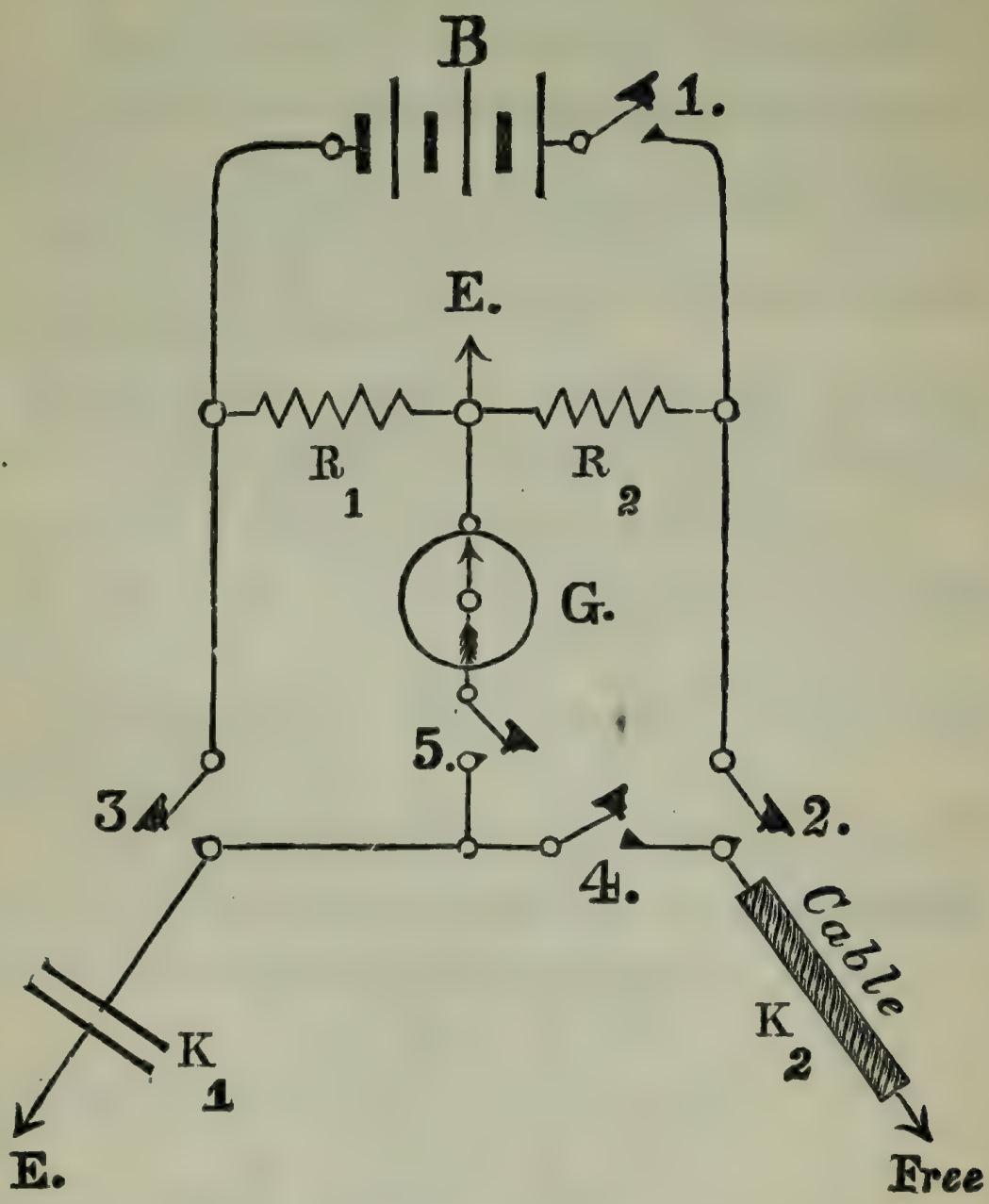
Then, if V_1 and V_2 = the potentials at the points of junction of the battery with the resistances, R_1 and R_2, we have

$$V_1 : V_2 :: R_1 : R_2.$$

2. By closing keys 2 and 3 simultaneously for a fixed time, the condenser and cable are charged to potentials V_1 and V_2 respectively.

If K_1 and K_2 be the respective capacities (in microfarads) of the condenser and cable, and Q_1 and Q_2 the charges given to them.

$$Q_1 : Q_2 :: V_1 K_1 : V_2 K_2.$$



Index to Diagram.

Where B	represents	Battery.
R_1	,,	Variable Resistance
R_2	,,	Fixed Resistance.
E	,,	Earth.
G	,,	Galvanometer.
K_1	,,	Standard Condenser.
K_2	,,	Cable or Condenser to be measured.
1, 2, 3, 4, 5	,,	Keys.

3. Upon releasing keys 2 and 3, close key 4 for a fixed time, so as to allow the charges given to condenser and cable to *mix*, then if Q_1 is not $= Q_2$, upon bringing the galvanometer into circuit by closing key 5, there will be a deflection. Change the ratio of R_1 to R_2 until, on trial, there is no deflection.

$$\text{Then} \quad V_1 K_1 = V_2 K_2,$$
$$\text{or} \quad V_2 : V_1 :: K_1 : K_2;$$

but from (1) we have

$$V_2 : V_1 :: R_2 : R_1,$$
$$\therefore R_2 : R_1 :: K_1 : K_2,$$
$$\text{or} \quad K_2 = \frac{R_1}{R_2} K_1 \ldots \text{microfarads.}$$

Lambert's key unites the keys 2, 3, 4, 5, and thus ensures accuracy in manipulation.*

In Absolute Measure the electro-static capacity of a condenser or cable may be measured by means of resistances without comparison with a standard condenser. For this test it is necessary to find by experiment :—

1. What resistance, R, in megohms, would be required to produce *unit* deflection, the same battery being used to charge the cable or condenser. (See pp. 72–74.)

The unit deflection with a mirror galvanometer is one division of the scale.

With a tangent galvanometer it is 45° (because tan. 45° = 1).

With a sine galvanometer it is 90° (because sin. 90° = 1).

* See Index for capacity test of cables by this method, pp. 152, 153.

2. Find the time, t seconds which the needle occupies in making half a complete oscillation. This is ascertained by setting the needle oscillating, and counting the number of times it passes across the meridian in a minute, or other observed interval of time.

3. Charge the cable or condenser and observe d, the deflection of the needle. If d is read off in degrees, the electro-static capacity is

$$K = 2\frac{t \sin. \frac{d}{2}}{\pi R} = \cdot 6366\frac{t \sin. \frac{d}{2}}{R} \text{ microfarads.}$$

If d is read off in divisions of an astatic mirror galvanometer scale, when the deflections are proportional to the current, then,

$$K = \frac{\cdot 3183\, d\, t}{R} \text{ microfarads.}$$

Example with mirror galvanometer :—

B = Battery 8 cells.
R = 5000 megohms.
t = 10 seconds.
d = 250 divisions.

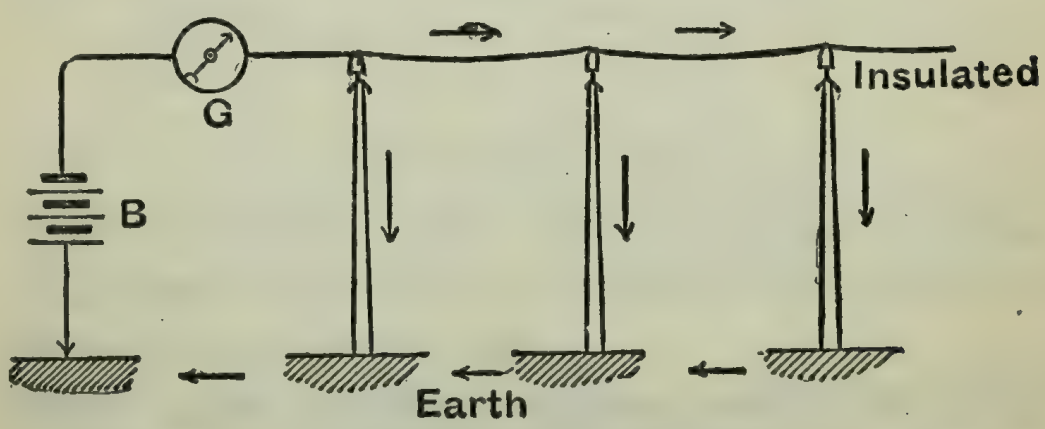
$$\therefore K = \frac{\cdot 3183 \times 250 \times 10}{5000} = \cdot 1591 \text{ microfarads.}$$

AERIAL LINES.

INSULATION RESISTANCE.—The insulation of land lines is got by the substitution test, p. 91; the insulation resistance of the line taking the place of R_1. Neglecting the resistance of the tangent galvanometer, G, as well as that of the battery, r, formula becomes

$$R = \frac{d_1}{d} R_1,$$

d and d_1 being deflections on the tangent scale. In making the test, connect the battery, galvanometer, and standard resistance, R_1, (usually 1000 ohms) in circuit, and note the deflection, d_1. Multiply d_1 by R_1 to give the *constant.* Insert R, the leakage resistance of the line to be determined, in place of R_1 and note deflection, d. Divide the constant by d to get the value of R.



The fig. shows how d is obtained with R in circuit. The – pole of the battery should be to line as a + current tends to seal up faults.

Insulation Resistance per Mile = R × L,

where R = total insulation resistance.
L = length in miles.

It is usual to fix a standard insulation per mile; if the measured value is less, the line is considered faulty. The Post Office standard is 200,000 ohms per mile (see Index for Post Office system of testing).

CONDUCTOR RESISTANCE OF LINES.—The observed total or "absolute total resistance" is that measured with far end of the line to earth. The resistance of the conductor or wire can only be measured accurately in fine weather, when the resistance of the insulators is very high.

Loop Test.—By Wheatstone's bridge the far end of the line, 1, is to earth, and the corresponding terminal of the balance to earth, p. 141. When a parallel line, 2, is available, avoid the use of earth by connecting them together at the far end and measuring the resistance of the loop. This gives their united resistance. When a third line, 3, is available, the resistance of each is found as follows:—Loop 1 and 2, and take their joint resistance R_1. Similarly loop 1 and 3, 2 and 3, and take their joint resistances R_2, R_3. Let r_1, r_2, r_3 be the separate resistances of 1, 2, and 3. Then

$$r_1 + r_2 = R_1 : r_1 + r_3 = R_2 : r_2 + r_3 = R_3.$$

$$\text{and } r_1 = \frac{R_1 + R_2 + R_3}{2} - R_3$$

$$r_2 = \frac{R_1 + R_2 + R_3}{2} - R_2$$

$$r_3 = \frac{R_1 + R_2 + R_3}{2} - R_1.$$

Correction for Earth-Currents.—Measure the resistance with a copper, +, current; then with a zinc, −, current. Let R_c and R_z be the respective values of the variable resistance, a and b the arms of Wheatstone's bridge, x the resistance required. Then, approximately,

$$x = \frac{b}{a} \sqrt{R_c R_z}$$

—*C. Dresing.*

Accurately

$$x = \frac{(R_c + R_z)\left\{r\left(1 + \frac{a}{b}\right) + a\right\} + 2 R_c R_z}{2\left\{r\left(1 + \frac{a}{b}\right) + a\right\} + R_c + R_z}$$

—*Kempe.*

To keep the deflections on the same side of scale on reversing the battery, transpose the galvanometer connections by means of a switch.

Resistance of an Earth.—With two lines (1 and 2) the resistances of the earths are found by Wheatstone's bridge. Loop the wires at their far ends and measure, $r_1 + r_2$, the resistance of the loop. Next, earth line 1 at its far end, and measure the resistance of line and earth, R_1. Then, earth line 2 at same place, and measure the resistance of line and earth, R_2. Then the resistance of the earth,

$$R_E = \frac{r_1 + r_2 + R_1 + R_2}{2} - (r_1 + r_2).$$

Resistance of each Line.—It is also evident that r_1, the resistance of line 1,

$$= \frac{r_1 + r_2 + R_1 + R_2}{2} - R_2.$$

Similarly r_2, the resistance of line 2

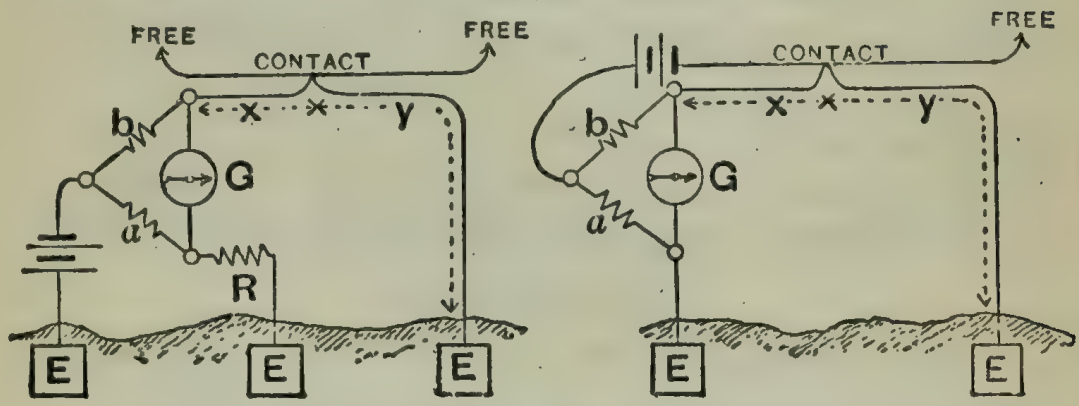
$$= \frac{r_1 + r_2 + R_1 + R_2}{2} - R_1.$$

Schwendler's Method.—Take two auxiliary *earths* and measure the resistance between each of the three pairs of earths, taking the mean of positive and negative readings. Let R_1, R_2, R_3 be the observed resistances, then the earth res.,

$$R_E = \frac{R_1 + R_2 - R_3}{2}.$$

This is the method generally adopted.*

Localising Contacts.—*Prof. Ayrton, F.R.S.*



1. Join up, as in left-hand fig., applying Wheat. Bridge to that line whose gauge and res. you know most about, and balance, when $a\,(x + y) = b\,R$.

If $a = b$, then $x + y = R$.

2. Join up, as in right-hand fig., and balance again, when

$$a\,x = b\,y\,;\ \text{or}\ \frac{x}{y} = \frac{b}{a}$$

$$\therefore\ \frac{x}{x + y} = \frac{b}{b + a} \qquad \text{Hence } x = \frac{b}{a + b}\,(x + y).$$

Substitute $x + y$ from first test, and so get the value of x. Thomson-Varley Slides may be used instead of Bridge.

* See Index for Lightning Conductor Tests.

TESTS USED IN INDIA.

By R. S. Brough.

LINE TESTING—*Schwendler.*

Let W = measured circuit resistance (*i.e.*, line + relay + earth resistance).

w = measured conduction resistance (*i.e.*, line + earth resistance, with relay out).

I = measured insulation resistance. (*i.e.* + leakage resistance, with end free).

Then the following inequality must hold

$$w < W < I.$$

Let i = true insulation res. (*i.e.*, leakage res.) of whole line.

L = ,, conduction ,, up to resultant fault.

l = ,, ,, ,,

r = true resistance of receiving instrument at distant station corrected for temperature.

Then $$i = \sqrt{\frac{(I - W)\,(I - w)\,r}{W - w}}$$

$$L = I + \frac{(I - W)\,r}{W - w} - 2i$$

$$l = I - i$$

and $\frac{l}{L}$ should be positive and less than unity.

When, $$l = \frac{L}{2}$$

$$i = \sqrt{I\,(I - w)}$$

$$L = 2\,(I - i)$$

and $$I\frac{(W - w)}{I - W} \text{ should be } = r.$$

Let n = number of miles the line is in length, then insulation per mile $= n \times i$.

Let m = the "reduced length" of the line in terms of the standard wire, then conductor resistance per mile $= \frac{L}{m}$.

FAULT TESTING.—*Earths.*

I. SINGLE LINE.—*Blavier's* formula,

$$x = w - \sqrt{(I - w)(L - w)}.$$

Schwendler's formula,

$$x = I - \sqrt{\frac{(I - W)(I - w)\,r}{W - w}}$$

II. DOUBLE LINE. — *Loop test.* — (Loop $= w''$: localisation $= w'$).

$$x = \frac{a'\,b''\,w'' - a''\,b'\,w'}{a''\,(a' + b')}$$

When $a'' = a' = a$, and $b'' = b' = b$,

$$x = \frac{b\,(w'' - w')}{a + b}$$

When $a = b$

$$x = \frac{w'' - w'}{2}$$

Correction for "partial" earth.—*Schwendler.*

Let $d = \frac{\text{resistance of fault to be localised}}{\text{resistance of resultant fault}}$

Then $$x = \frac{a\,w'' - b\,w'}{a + b}\,(1 + d) - \frac{d\,w''}{2}$$

When $a = b$,

$$x = \frac{w'' - (1 + d)\,w'}{2}$$

III. CONTACTS.—When a third wire is not available.—(*Schwendler.*) (Distant ends looped $=w'$: distant ends insulated $=w''$.)

$$x = \frac{w' - \sqrt{(L' + L'' + w')(w'' - w')}}{m' + m''}.$$

Where L′ and L″ are the absolute, and m' and m'' the per mile, resistances of the two wires in contact.

When $w' = w'' = w$, $x = \dfrac{w}{m + m'}$

When $m' = m'' = m$, $x = \dfrac{w}{2\,m}$.

When a third wire is available—(*Higgins*). Put one of the wires in contact to earth, and localise the "contact" as an earth by the loop test. (See p. 168.)

IV. DISCONNECTIONS. — By the insulation method.

$$x = \frac{I}{i} \cdot L \begin{cases} x = \text{distance to break.} \\ i = \text{insulation resistance to break.} \\ I = \text{total ,, ,, of line.} \\ L = \text{,, length of line.} \end{cases}$$

By the capacity method

$$x = \frac{s}{S} \cdot L \begin{cases} s = \text{capacity to break.} \\ S = \text{total capacity of line.} \end{cases}$$

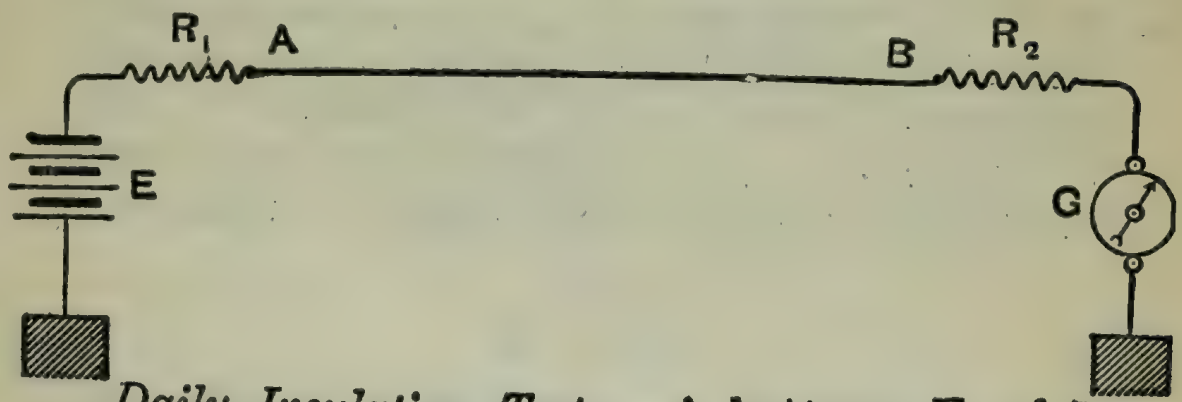
When a line contains several different gauges of wire, to find the resistance per mile of any particular gauge (*Schwendler*)

$$x_a = \frac{L}{d_a^2 \, \Sigma_1^n \dfrac{l}{d^2}}$$

Where L = res. of whole line having n gauges of diameters, $d_1 - d_n$, and lengths, $l_1 - l_n$.

System of Testing used in the British Postal Telegraph Department.

The tests in general use are:—"Daily Tests of the Lines for Insulation Resistance," "Monthly Tests of the Lines for Conductor Resistance," "Weekly Tests of the Batteries for Electromotive Force and Internal Resistance."



Daily Insulation Tests.—A battery, E, of 50 Daniell cells, is joined up through a resistance, R_1, of 10,000 ohms to one end, A, of the line A B. At the further end, B, the line is connected through another resistance, R_2, of 10,000 ohms to a galvanometer, G, whose resistance is 320 ohms, which resistance is approximately the same as the resistance of the battery, E. The galvanometer, G, is adjusted so that a current from 1 Daniell cell (1·07 volts), through a total resistance of 1,070 ohms, gives a deflection of 25°. The average conductor resistance of the lines is taken to be 1,000 ohms.

The "Total Insulation Resistance," R_i, of the line A B is obtained from the formula

$$R_i = \frac{1}{\frac{\cdot 0002131}{\tan. D^\circ} - \cdot 00018484},$$

where D° is the deflection observed on G.

A table is used which shows the insulation resistance corresponding to any particular deflection.

Conductor Resistance.—This test is made by means of an ordinary Wheatstone bridge, a measurement being made with zinc to line and another with copper to line. In cases where a large number of wires running over the same route have to be tested, the wires are looped and the resistances of the loops measured so as to avoid errors due to earth-currents, &c.

Battery Testing.—The battery, E (see next fig.), is joined up in circuit with a high resistance, R, the value of the latter being proportioned to the number of cells to be tested. R actually consists of 6 resistances of the following values:—1,070, 3,210, 4,280, 8,560, 17,120, and 34,240 ohms. A resistance of 750 ohms is included in the galvanometer (which is the same as that used for the Daily Insulation Tests); this resistance, together with the resistance of the galvanometer coil (320 ohms), makes G equal to 1,070 ohms. The value of the resistance, R, is such that

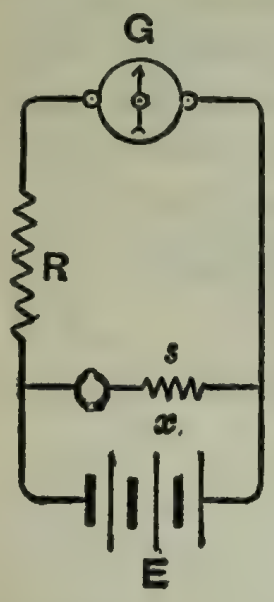
$$\frac{R + G}{n}$$

is constant, n being the number of cells to be tested and being a multiple of 5. The galvanometer is adjusted, as for the Daily Insulation Test, so that 1 Daniell cell through 1,070 ohms gives a deflection of 25°. The electro-motive force per cell of the battery is then given by the formula

$$e = \frac{\tan. D^\circ \times 1{\cdot}07}{\tan. 25^\circ} \times \frac{R + G}{G n}.$$

For Daniell batteries $\frac{R + G}{G n}$ is made $= \frac{2}{5}$, so that $e = \tan. D^\circ \times {\cdot}91786$.

For Bichromate batteries $\frac{R + G}{G n}$ is made equal to $\frac{4}{5}$, so that



$$e = \tan. D^\circ \times 1{\cdot}83572.$$

The total resistance, x, of the battery is obtained by shunting the deflection, D°, down to d°, by means of the shunt, S; the resistance, x, is then given by the formula

$$x = s\left(\frac{\tan. D^\circ}{\tan. d^\circ} - 1\right).$$

s consists of the following resistances:—10, 25, 50, 100, 200, and 300 ohms. Tables are used which show at a glance the electro-motive force per cell of the battery, corresponding to any particular deflection, D°. A table is also used, which shows the value of $\left(\frac{\tan. D^\circ}{\tan. d^\circ} - 1\right)$ corresponding to any particular deflections, D° and d°.—*H. R. Kempe.*

Testing Insulators.

The insulators are placed in water with the metal bolts upwards in a lead-lined trough. The water should come to within half an inch of the lip inside and outside of the inner and outer sheds. They are allowed to soak for several hours.

Parts of insulators which are cemented together are tested separately before they are cemented.

There are three tests for a D. S. insulator:—

1. Of the outer shed, by applying the test rod to the water between the two sheds.

2. Of the crown, by applying the rod to the water in the socket.

3. Of the inner shed, by coupling the water in the trough to that between the two sheds by means of a copper fork with an ebonite handle, and then applying the rod a second time to the water in the socket.

A gas grid, or hot iron, is used to dry the lips of the insulators, if the atmosphere is damp and likely to make surface leakage.

A Thomson galvanometer is used, which gives a unit or one degree deflection with one Daniell cell through 500 megohms; and with 140 cells, gives one degree deflection through 70,000 megohms. This constant is high enough to detect a bad insulator. Along with the galvanometer a key is used, which in its normal position shunts all current from the galvanometer coils, and saves them from injury in the case of a very faulty insulator.

There are three plungers in the key which severally shunt $\frac{9999}{10,000}$, $\frac{99}{100}$, and nil of the current.

The galvanometer, batteries, and leads to the testing rod should be well insulated.

Minimum Insulation.—The minimum insulation resistance which each insulator should have, depends greatly on the length of line on which it is to be used. For a line of 100 miles long, each insulator should at least give a resistance of 500 megohms, or only 1° deflection on the Thomson galvanometer; for a line of 10 miles 50 megohms, or 10° deflection will do.

SUBMARINE CABLES.

TESTS DURING CONSTRUCTION, for copper resistance, insulation resistance, and capacity. If the capacity and copper resistance are taken first, a low battery power is used to prevent "polarising" of the dielectric. Capacity is usually taken by the Thomson test; copper resistance by the Wheatstone bridge, and insulation resistance by the galvanometer, or the electrometer (see Index for these methods). The results are worked out by the help of tables, and booked in proper forms. The copper and insulation resistances are corrected to 75° Fah.

Core is usually made in lengths of about 2 knots which are coiled on wooden drums, and placed in water at 75° F. or 24° C. After at least 24 hours' immersion, to bring the core to this temperature, the coils are tested, and the results entered in blank forms. The copper resistance form gives the date, No. of coil, length in knots, total resistance, resistance per knot, percentage, conductivity, and remarks. The capacity and insulation forms give similar data, the latter giving also particulars of the test, such as battery power, deflection from 1 cell through 10,000 ohms with $\frac{1}{1000}$ shunt, deflections after 1 and 2 minutes' electrification, total insulation resistance and resistance per knot after 1 minute's electrification. Another form gives the date, No. of coil, lengths in yards and knots, total weights of copper and dielectric, weight per knot of copper and dielectric, and their differences from the contract weights in lbs. per knot.

During the Sheathing.—A continuous test by

galvanometer or electrometer is applied. Each joint of a coil to the cable is tested at least 24 hours after it is made.

The estimated percentage conductivity of the cable is assumed to be the arithmetic mean of the percentages of each 2-knot length at 75°. The estimated insulation resistance is the reciprocal of the sum of the reciprocals of the insulation resistances of the coils at 75°.

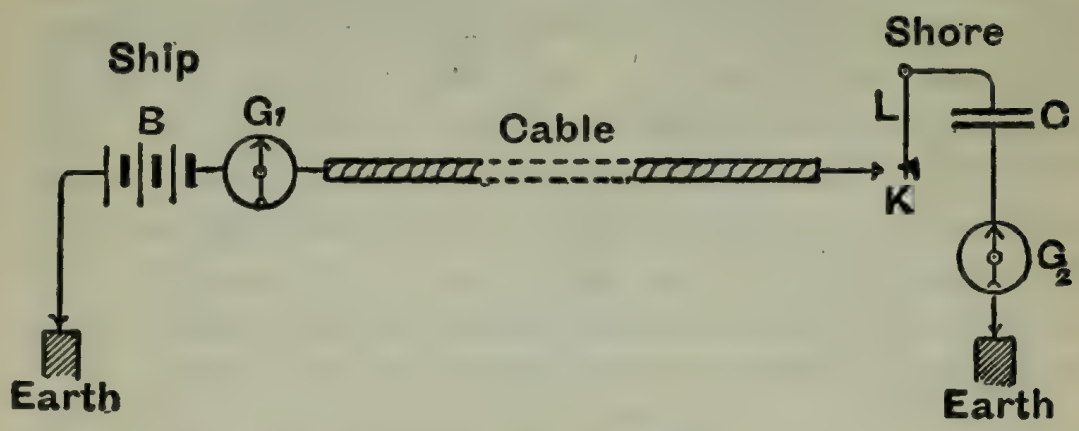
Daily tests are taken of the capacity, copper, and insulation resistance of all the pieces of cable made or being made. The insulation test is usually made with both copper and zinc currents, the cables being at least 1 hour to earth between. Special insulation tests are sometimes made, keeping the current on for half-an-hour, and noting the deflection at the end of each minute.

During shipment.—A continuous galvanometer or electrometer test is applied.

The final test of the finished cable before sailing should be made with the highest battery power allowable, 300 to 500 volts E.M.F.

During the voyage daily tests for capacity, copper, and insulation resistance, of all the cables on board, should be made as in the factory.

Tests during Laying.—The connections for a continuous test during the laying of a short cable are shown in the fig. On the ship the cable is connected to earth through a marine galvanometer, G_1, and battery, B, of about 100 cells. On the shore the end of the cable is connected to the insulated contact of a key, K, the lever of which, L, is ordinarily on the other contact as shown. This lever is connected to a condenser, C, and a galvanometer, G_2, to earth.



The leakage of the cable deflects the needle of G_1, and this deflection is constantly watched. A sudden fall of insulation, causing the spot of light to fly off the scale, indicates a fault, and the ship must be stopped. A break in the conductor alone would be indicated by a sudden fall in the deflection. These movements of the needle are not to be confounded with those due to the oscillation of the ship, which cause magneto-electric currents in the coils of cable in the tanks.

On shore, every 5 minutes, either by clock-work, or by hand, the lever, L, is moved to the cable stop of the key, K. This charges the condenser, C, and causes a throw of the galvanometer needle there. The extent of throw indicates that the cable is sound; if less than usual a fault has appeared. This periodical action is also indicated by a slight throw on the ship's galvanometer. At the end of every hour, the ship reverses its battery, so that the direction of the throws is changed.

To enable the ship to speak to the shore, instructions are given that if at the end of an hour, the throws from the condenser on shore

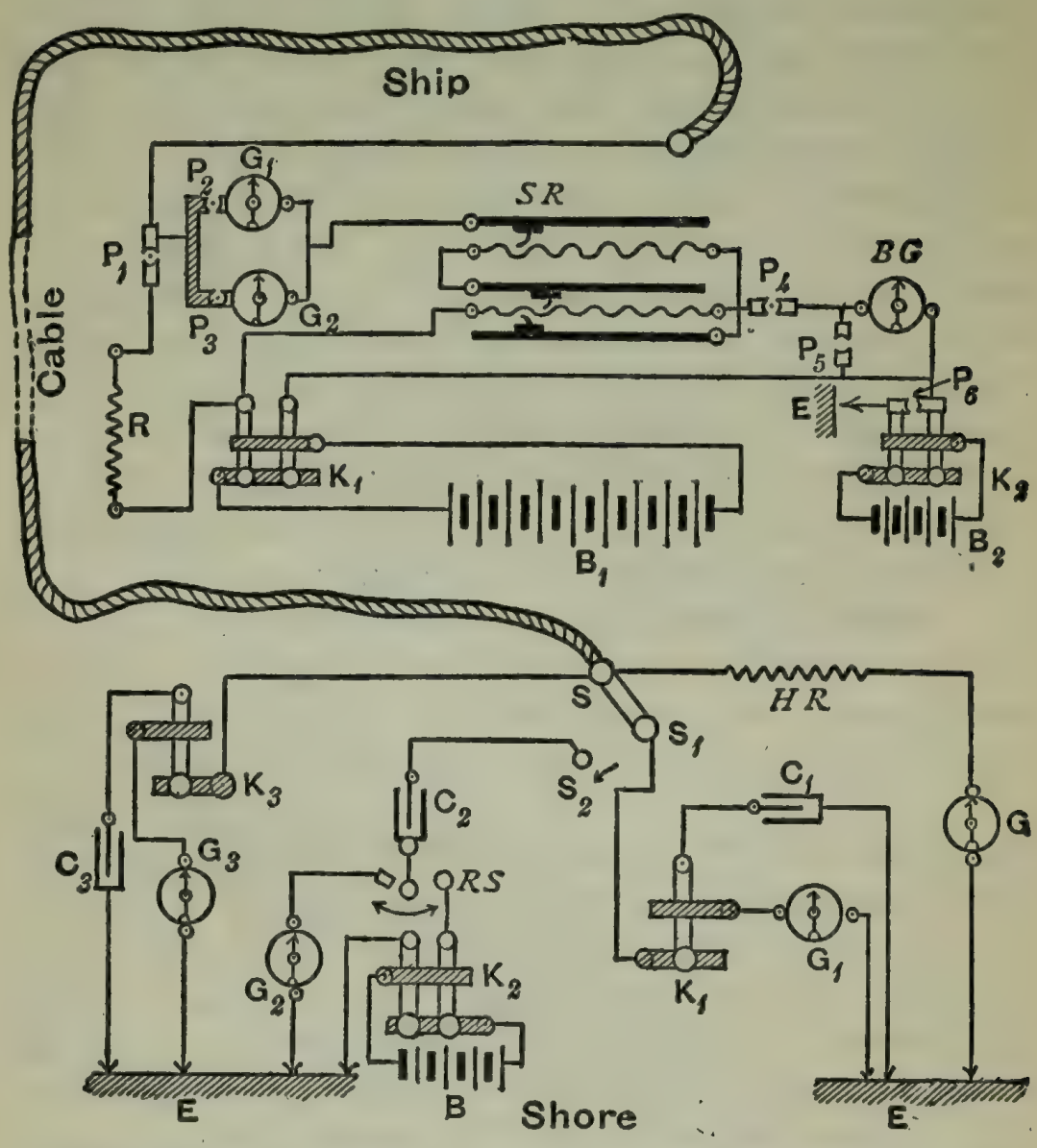
are not reversed, or if they are reversed before the expiry of the hour, it means that the ship wishes to speak. The shore then puts the cable in connection with the speaking instrument. On the other hand, the shore calls the ship by striking the lever, L, repeatedly on the cable contact, thereby causing successive throws on the ship's galvanometer. The ship then prepares to speak the shore.

Compound Cables.—When the cable has more than one conductor, these should be connected "in series," that is, in one continuous length, and the continuous test applied.

For Repairing Expeditions, and when laying very short cables, a simple and efficient method is, for ship to take, continuously, alternate insulation and C R tests, shore freeing cable 4 minutes, and earthing 1 minute, through his speaking instrument; commencing to free at every 5th minute. Res. of speaking instrument being known to ship.

Willoughby Smith's Electrical Connections on ship and shore, as used by the T. C. and M. Co. when laying long cables.

Referring to figs., ship controls all operations. Continuous readings are taken on ship for dielectric resistance, by means of slide resistance coils, S R, as explained at pp. 102 to 106; the apparatus in use being battery, B_1, 100 cells; key, K_1; high res., R; galvanometer, G_1; slide res. coils, S R, with plugs P_1, P_2, P_4, P_5, and P_6 inserted. Ship reverses battery, B_1, every 15 minutes. For speaking, galvanometer, G_2, is used by removing plug from P_2 to P_3; and battery, B_2, with key, K_2, plug 6 removed, is used as a signalling battery.



Galvanometer, B G, with plug, P_5, removed, is for ascertaining the E. M. F. of battery, B_1, in the way described at p. 90.

On shore the cable is always connected by terminal, S, to earth through a very high selenium resistance, H R, of about 30 megohms, and galvanometer, G, by which the permanent deflection and reversals every 15 minutes due to ship's battery are noted. This serves as a continuity test, as well as a means of ship calling up shore.

The cable is also permanently connected by S, to key, K_3, by means of which condenser, C_3, is charged, and discharged through galvanometer, G_3, without a shunt every 15 minutes, which gives the potential of the line.

Every 5 minutes shore takes discharge readings on galvanometer, G_1, by means of key, K_1, connected to switch at S_1. and condenser, C_1; the deflections so caused on ship's galvanometer, G_1, are noted on board as continuity tests. If shore wishes to speak with ship minute discharges are taken on G_1, and when attention is secured shore switches over cable to S_2, and uses the speaking galvanometer, G_2, in combination with battery, B, key, K_2, condenser, C_2, and receiving switch, R S.

On ship, copper resistance is obtained when desired by slides, and on shore by Wheatstone bridge connections not shown in diagram.

All shore tests are communicated to ship.

Warren's Method for finding faults in unsheathed core. Coil the core on two insulated drums close together, one-half on each drum. Connect one end of the core to the insulated quadrants of an electrometer, the other quadrants being to earth, and the other end of the core insulated. Charge the core by applying one pole of a battery to the conductor, the other pole being to earth, and the drums also connected to earth. Then disconnect the drums from earth, and the battery from the conductor. The insulation should be such that no loss is shown on the electrometer after a few minutes; then, if the earth-wire be applied to one drum after the other, the drum causing the largest defleo-

tion will contain the fault. The core is coiled off the faulty drum to the other, and the test repeated until the fault is found. To prevent conduction from one drum to the other, the core should be cleaned, rubbed, and thoroughly dried for a length of 6 or 8 inches between the drums before each test. When the fault lies between the drums, its position is found by cleaning the core on each side and touching the place with the earth-wire to see if there is a fall on the electrometer. A galvanometer joined up for insulation test may be used instead of the electrometer.

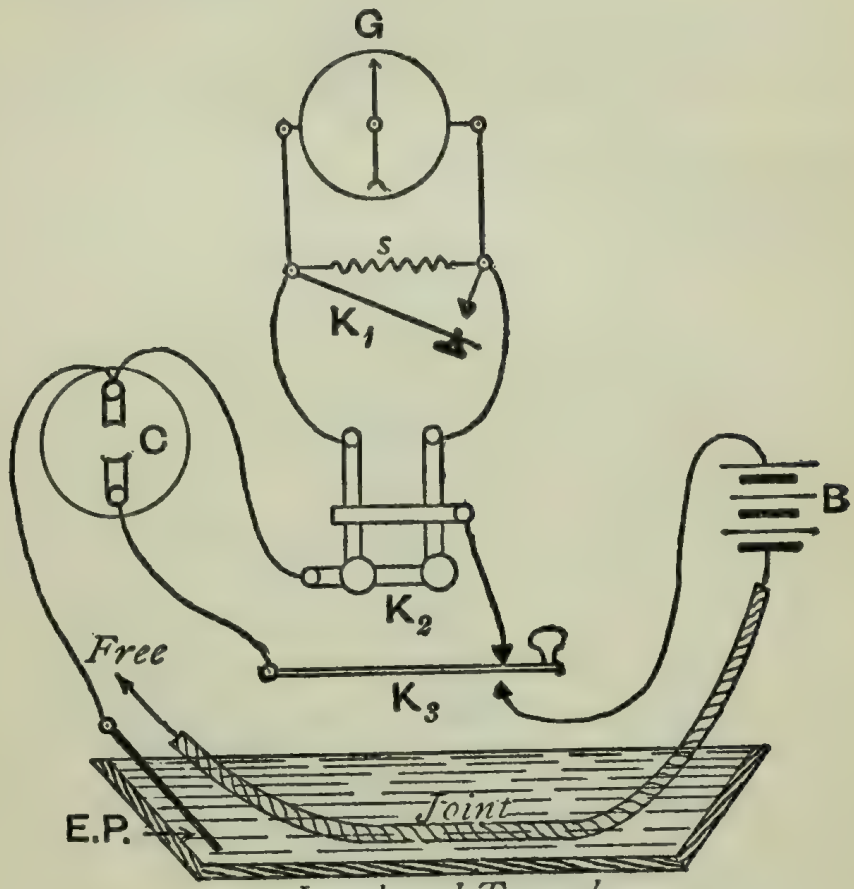
When the core is so long that it cannot be coiled on two drums, it may be coiled on one until the fault is on the drum. This plan is useful with "served" core.

Siemens' Method.—Place the core in a strong Whitworth steel cylinder, and subject it to a hydraulic pressure equal to the maximum depth to which it will be ultimately subjected to when submerged. This bursts any air-holes, and renders minute faults more apparent than when electrical tests are taken of the core not under great pressure. When this method is adopted the 3 or 4 coatings of guttapercha may be put on at one operation.

Cleaning Core Ends.—The ends of guttapercha cable, core, or leads, are best cleaned for testing by paring down the guttapercha with a clean sharp knife. The ends may be dipped for a moment into boiling paraffin wax to secure more perfect insulation. India-rubber core, after being pared with scissors may be rubbed with a clean cloth soaked in wood-naphtha.

TESTING JOINTS.

ACCUMULATION METHOD (*Clark*).—In the factory, new joints, when cool, are tested against a standard length of good core of the same size and material.



Insulated Trough

G = Astatic galvanometer of high resistance.
s = Shunt for galvanometer.
K_1 = Short circuit key for G and s.
K_2 = Reversing key.
C = Condenser of ½ to 1 microfarad.
E P = Copper earth plate.
K_3 = Trigger key (Webb's).
B = Battery of 100 to 200 Daniell cells.

1. The joint is placed in a *thoroughly well insulated trough*, containing salt water and copper plate attached to a condenser with an insulated lead. The joint is then charged with

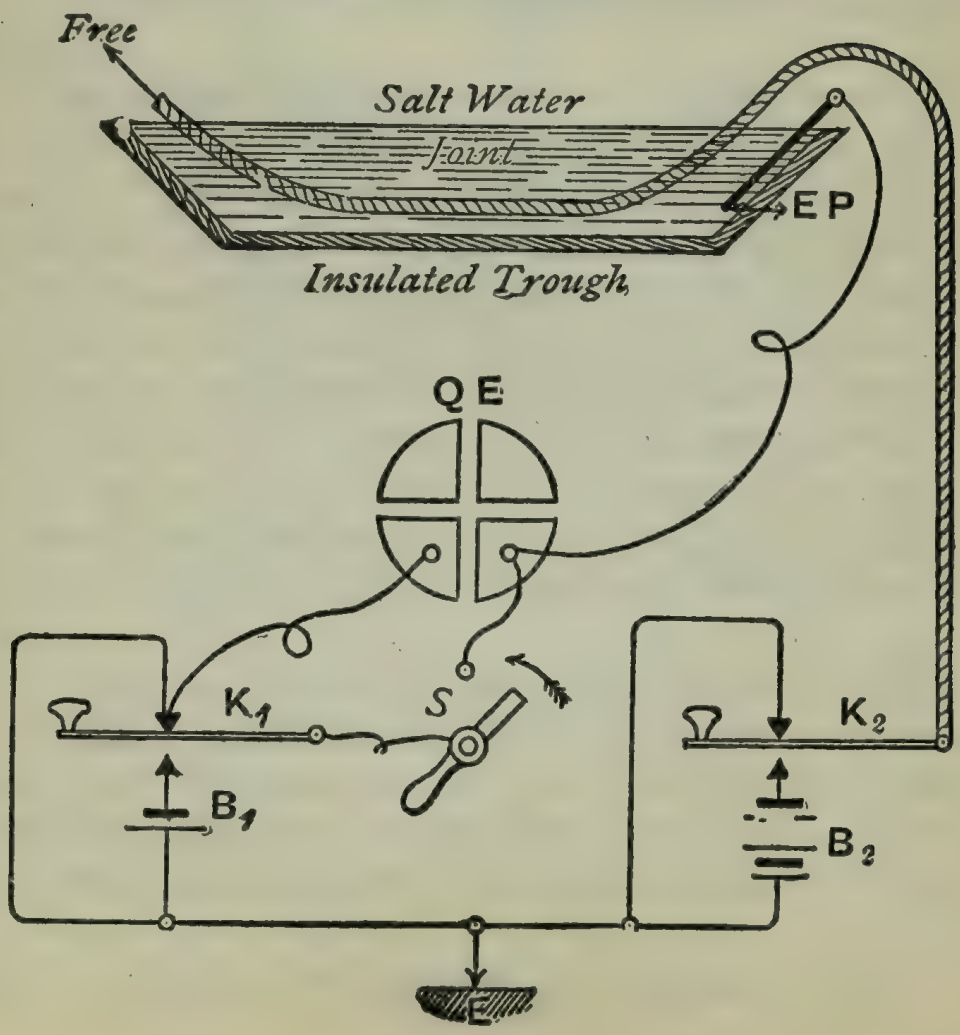
300 Daniell cells, further end being free, and the leakage through the joint to the plate and condenser noted after a half-minute charge, by the discharge deflection on a sensitive Thomson's astatic mirror galvanometer.

Close K_3 for the time specified, and charge the joint, then liberate it, and discharge the condenser through G.

2. Five to six feet of good core are treated in the same way, and if the joint is not worse than the core it is passed.

Joints on board ship during an expedition are seldom if ever tested, but they are made by thoroughly experienced and reliable workmen.

JOINT TEST BY ELECTROMETER.



By Electrometer.—The tendency of a condenser to absorb electricity renders the electrometer test preferable to the foregoing, when convenient. The connections for it are shown in the figure, where Q E is the quadrant electrometer.

Before putting in the joint, the insulation of the trough is tested by depressing key K_1 and closing switch, S, on its *well-insulated* stop. This charges the quadrants of the electrometer with the 10-cell battery, B_1, and causes a steady deflection of the needle. Keeping K_1 depressed, now open switch, S, and watch the deflection for two minutes, to see if there is any fall due to leakage of the quadrant charge to earth through the trough. If the fall is only two or three divisions of the scale, the insulation of the trough is good.

The electrometer is now discharged by releasing K_1 and closing switch, S. The joint is placed in the trough and connected to K_2, as in the figure. Switch, S, is again opened and K_2 depressed. This charges the joint with the 300-cell battery, B_2, and causes a sudden deflection of the needle. It is usual to note this deflection as indicating that the connections are all right.

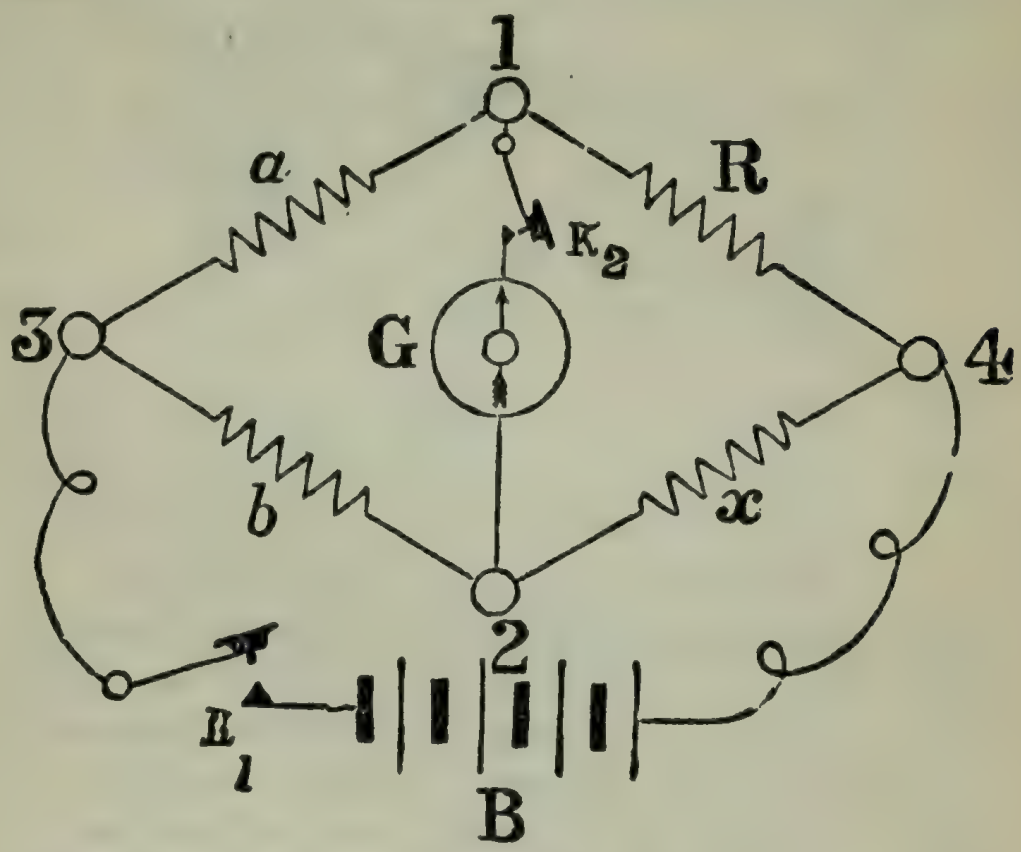
Keeping K_2 depressed, switch, S, is now closed to discharge the electrometer, and then opened. The scale of the electrometer is then watched, as the current leaking through the joint accumulates in the trough and causes a rising deflection of the needle. This deflection is noted at the end of one and two minutes after opening the switch, and is compared with that given by a piece of perfect core instead of the joint.

COPPER RESISTANCE.

By Wheatstone's Bridge.

See p. 96 for ordinary C R. Test by Bridge.

Arrangement of balance for reading off directly the resistances of copper per knot, without calculation.



a = *Constant* resistance of 2,029 ohms.
R = Variable resistance box, which is adjusted each time to exactly as many ohms as there are yards in the length of the cable.
b = An adjustable resistance expressing the resistance of the conductor in ohms per knot.
x = The conductor of the cable.

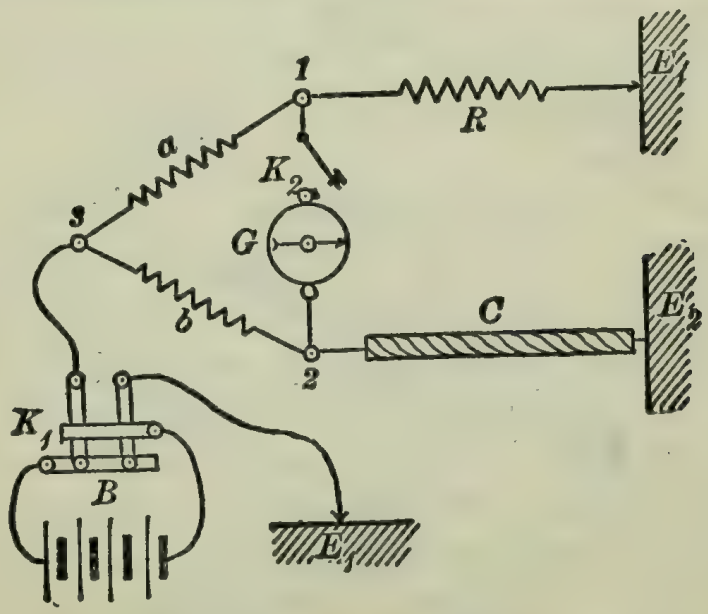
The cable (whose length, L, in yards is known) is first inserted in its place, x, then the box, R, is arranged to have L ohms resistance; when a balance is obtained, suppose the whole resistance of the conductor to be x ohms, then

$$a\,x = b\,\mathrm{R} \therefore b = \frac{a\,x}{\mathrm{R}} = \frac{2{,}029\,x}{\mathrm{L}} =$$

the resistance of the conductor in ohms per knot.

This method is very convenient when the conductors are measured at the same temperature, such as the separate lengths of core in the tanks at 75° Fah., before being passed for sheathing, as it saves much time in reducing the observed values. For such measurements the resistance box, *b*, should, if possible, be constructed with values from 0·01 to 50 ohms.

Copper Resistance of a Submerged Cable.



1. Join up as in fig., and obtain "false zero," *i.e.*, the deflection on galvanometer, G, due to cable or earth-currents. The battery, B, being out of circuit, the earth-current flows on depressing K_2 partly through galvanometer to earth, and partly through resistance, R, *which should be approximately* = *x*.

2. Apply + or − pole of battery, B, by key,

K_1, balancing the resistance, R, to the "false or cable current zero."

When $x = R\frac{b}{a}$, the copper res. of cable.

If the earth-currents are very variable, causing a difference between the results obtained with + and − currents,

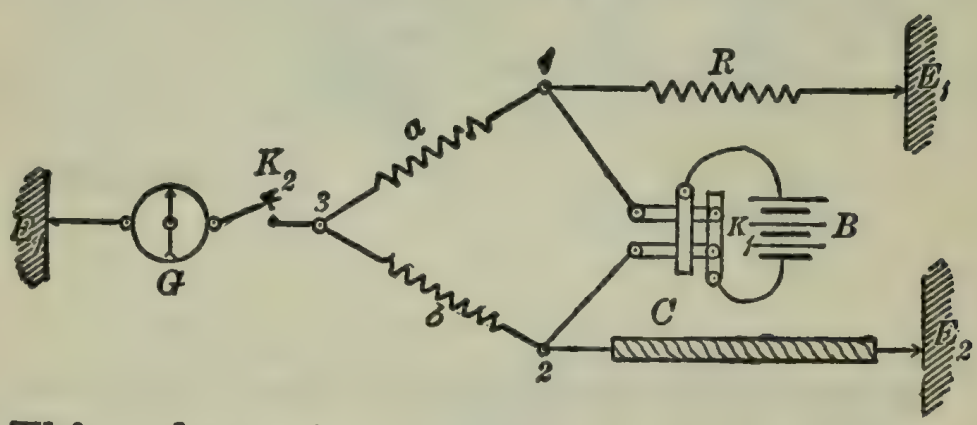
Let c = resistance obtained with + pole.
z = " " − "

Then,

$x = \frac{b}{a} \cdot \sqrt{z \times c}$, the mean copper resistance.

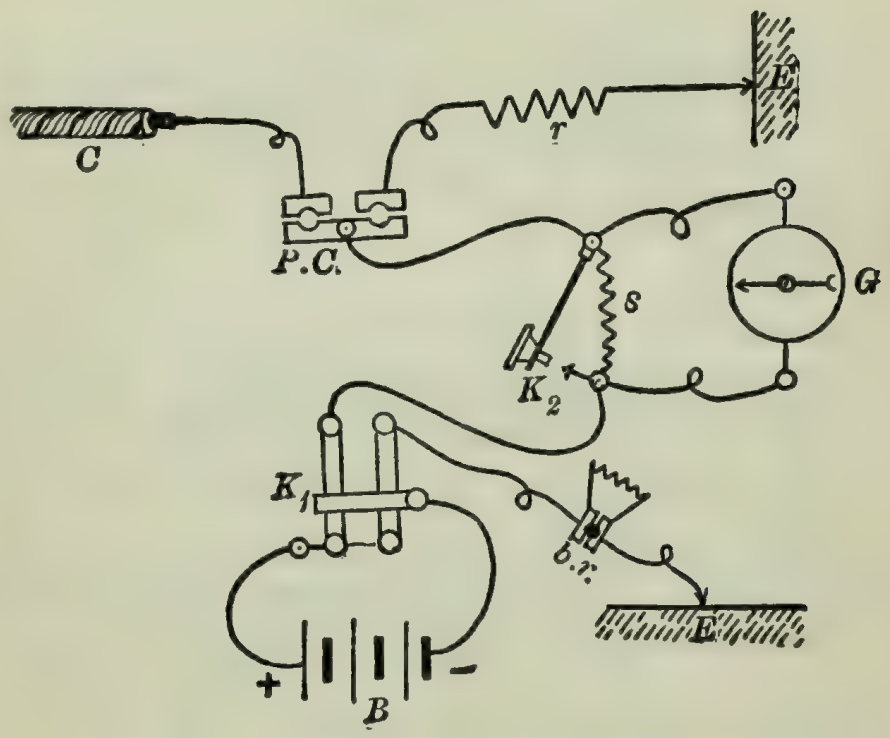
The arithmetical mean of the readings is inaccurate, more especially if the + and − readings differ considerably. *Always use the formula.*

In the following fig. the positions of the battery, B, and galvanometer, G, are interchanged. The reference numbers and letters are the same in both figs. as in the fig., pp. 96, 140.



This plan of connections for Wheatstone bridge is sometimes more sensitive than the former. The battery, B, must be well insulated to prevent earth leakage.

Copper Resistance by direct deflection and reproduction method, with Sir Wm. Thomson's galvanometer, suitable for tests of long cables.



Index to Diagram.

Where B represents the battery 1 to 10 cells.

K_1	,,	Battery key.
G	,,	Galvanometer, dead beat mirror.
s	,,	Shunt (which is not always necessary).
K_2	,,	Short circuit key for galvanometer.
P C	,,	Plug commutator.
C	,,	Cable or electric light conductor.
r	,,	Resistance box.
b r	,,	Resistance equal to battery resistance, only required when earth-currents present.
E	,,	Earth.

Method of taking Test.

1. With far end of conductor to earth, and plug in left-hand hole of P C, apply battery to conductor C, and note deflection on scale.

2. Shift plug to right-hand hole of P C, and apply same pole of battery to resistance r, altering it until the same deflection is obtained as with conductor C.

3. Repeat 1 and 2 with other battery pole. A series of readings may be taken with alternate poles to conductor, and the mean deflections afterwards reproduced through r.

NOTE.—If a shunt is used it should not be altered while reproducing deflections through r, unless the resistances at disposal are either too small or too large to give the exact deflection required, when the multiplying power of shunt or shunts used $\frac{G+s}{s}$ must be taken into account. The position of the scale, galvanometer, or its controlling magnet, must not be shifted until the deflections have been reproduced. If testing the copper resistance of a submerged cable when earth-currents are present, first note the deflection produced by the earth-current through G and br to earth by removing plug br, and *add* this deflection to that produced by battery through C if *against*, or *subtract* it if *with* battery current for the true deflection to be reproduced. In testing a long cable do not bring G into circuit until the charge has had time to become uniform—10″ for 500, 20″ for 1000, and 40″ for 2000 knots—for fear of damaging suspension of mirror or altering zero.

If there is any difference between the resistances obtained with + and — poles, the true copper resistance of the conductor will be obtained by taking the *harmonic* mean of the two results.

Or,

$$x = \frac{2\,z\,c}{z+c}$$

Where x = true resistance.

z = resistance with − pole.

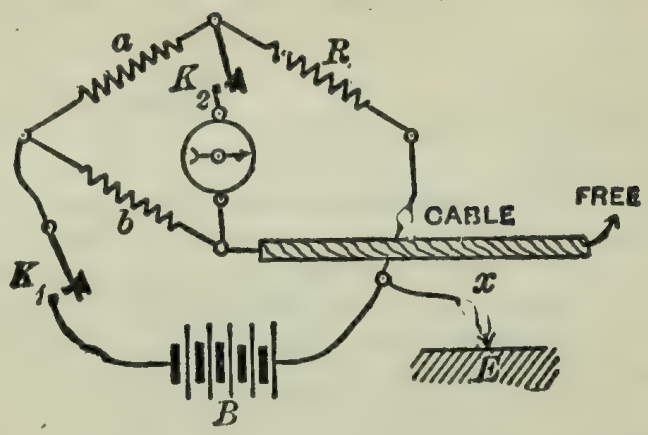
c = ,, ,, + ,,

F. Jacob.

INSULATION.

Balance for reading off the insulation resistance in megohms per knot, without calculation.

This method is analogous to that on p. 140, but is not so exact, on account of the difficulty of preventing heating of the coils.



a = *Variable* resistance box adjusted in each experiment to the same number of ohms, as there are knots length in the cable.

R = *Constant* resistance of one megohm.

x = Cable insulation resistance in megohms.

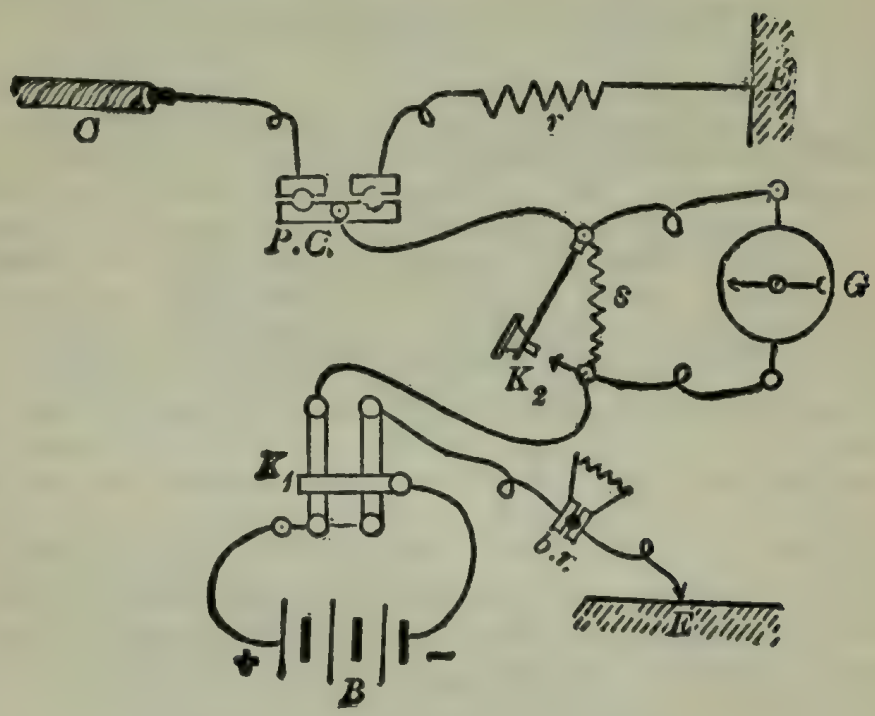
b = Resistance which, when a balance is obtained, represents the insulation resistance in megohms per knot.

In this case, the length of the cable being L knots, we have by bridge equation

$$a\,x = b\,\mathrm{R} \therefore b = \frac{a\,x}{\mathrm{R}} = \text{megohms per knot.}$$

For the periodical tests of a submerged cable whose total insulation resistance is about 1 megohm, this arrangement would be found convenient, in which case, a and R would be constant quantities, and the insulation resistance per knot would be read off directly from b.

Measurement of Insulation Resistance of Core or Cable by Direct Deflection with Sir William Thomson's Mirror Galvanometer.



Index to Diagram.

Where B represents		Battery 100 to 500 cells for factory, and 20 to 30 for cable station tests.
K_1	,,	Battery reversing key.
G	,,	Galvanometer high resistance dead beat or astatic.
s	,,	Shunt box.
K_2	,,	Short circuit key for G and *s*
PC	,,	Plug commutator.
r	,,	High resistance box.
b r	,,	Resistance equal to battery resistance, only required where earth-currents are present. *Seldom used.*
C	,,	Cable, core or electric light lead (freed at far end).
E	,,	Earth.

Method of taking Test.

1. *Preliminaries.*—Free far end of C, cut down near end, and test insulation of leading wires, which should be infinite; find battery resistance, *b r*, and note temperature.

2. *Deflection for Constant.*—Adjust shunt, *s*, insert plug in right-hand hole of P C, and obtain deflection, d_1, through high resistance, *r*, by depressing the (+) pole of K_1, and releasing K_2. Note that you get the same deflection with (—) pole of K_1, if not, see at once to battery, scale, and galvanometer. A key for reversing leads to galvanometer terminals may be used to get deflection always in same direction with (+) and (—) currents.

3. *Note Earth-Currents.*—If testing a submerged cable or one being laid, observe *earth-current* reading by removing (*b r*) plug, then inserting plug into left-hand hole of P C, and disconnecting *s*. Note whether the deflection is positive (+) or negative (—). It is usual to add or subtract from deflections d_2 these earth-readings, according as they may be against or with the battery current.

4. *Electrification Deflections.*—To charge, C, short circuit G by K_2, and depress (—) pole of K_1 at the exact minute. At half-minute release K_2, and note scale readings every 15 seconds for time required. The mean of readings observed at 45″, 60″, and 15″ give true deflection, d_2, for the 2nd, 3rd, 4th, 5th, &c., minutes respectively.

5. *Return Electrification Readings.*—Immediately after last reading with battery to cable, short circuit G by K_2, release K_1, and in 30″ begin to take earth-readings through, *b r*, releasing K_2, noting them every 15″. Add the mean return earth deflection for *first* minute to the mean deflection for *last* minutes charge to obtain true deflector d_2 for the first minutes electrification.

6. *Earthing, &c.*—Having earthed cable for a sufficient time to thoroughly discharge it, repeat 3, 4, and 5 with (+) pole of battery to cable. Rule 2 should then be repeated in order to see that B and G have remained constant.

7. *Magneto-Electric Currents.*—If testing cable on board a ship while she is pitching and rolling, the simplest way to get rid of the troublesome effects of magneto-electric currents due to the cable coils cutting the earth's magnetism, is by joining the two ends of the cable conductor together and taking a T insulated leading wire from the junction to the testing galvanometer. This plan is not practicable when paying out the cable.

Data for Constant.

$$\left.\begin{array}{l}\text{If B = battery res.}\\ \text{G = galvr. ,,}\\ s = \text{shunt ,,}\\ r = \text{high ,,}\end{array}\right\} \quad . \quad . \quad \text{in ohms.}$$

$$\frac{G\,s}{G+s} = \text{joint res. of G and } s$$

$$\frac{G+s}{s} = \text{multiplying power of shunt.}$$

Then . $R = \left(r + \frac{G\,s}{G+s} + B\right) \div 10^6$

= total res. in circuit in megohms, when obtaining deflection d_1, with full battery power.

And . . . . $d_1 \frac{G+s}{s}$

is the calculated deflection in divisions which would be obtained with full battery power through G if no shunt were used,

∴ *The Constant for the Galvanometer*—

$$= R\,d_1 \frac{G+s}{s}.$$

d_2 = deflection corrected for earth-current at any particular minute, using *no* shunt with galvanometer.

Absolute Insulation Res. of Cable in Megohms—

$$= \frac{\text{constant}}{d_2} = \frac{R\,d_1 \frac{G+s}{s}}{d_2}$$

For Insulation Res. per Knot multiply the absolute resistance by length of cable in knots.*

* See Index for tests and insulation resistance of recently submerged cable.

Example. — Test of recently laid cable.—*Jamieson.*

Length L = 632 knots.

Data for Constant.

High res. box corrected for temp.	$= r$	$= 1{,}004{,}220$ ohms.
Combined res. of G and s . . .	$= \frac{G\,s}{G + s} =$	940 ,,
Battery res. . .	$= B =$	410 ,,
Adding the above	$\therefore\ r + \frac{G\,s}{G + s} + B =$	1,005,570 ,,

$\therefore$ *Total res.* R = 1·0056 megohms.

Multiplying Power of Shunt.

$$\left.\begin{array}{l} G = 7000 \text{ ohms} \\ s = 1086 \text{ ,,} \end{array}\right\} \therefore \frac{G + s}{s} = \frac{7000 + 1086}{1086} = 7{\cdot}445.$$

Deflection $d_1 = 306$ divisions.

Constant.

$$= R\,d_1 \frac{G + s}{s} = 1{\cdot}0056 \times 306 \times 7{\cdot}445 = 2290.$$

i.e., the full battery power would produce 2290 divisions deflection on the galvanometer scale with 1 megohm in circuit if no shunt were used.

Deflection with Cable, 5th Minute.

(−pole) $d_2 = 248$ divisions after correcting for earth-current.

Absolute Insulation Resistance.

$$= \frac{\text{constant}}{d_2} = \frac{2290}{248} = 9{\cdot}233 \text{ megohms.}$$

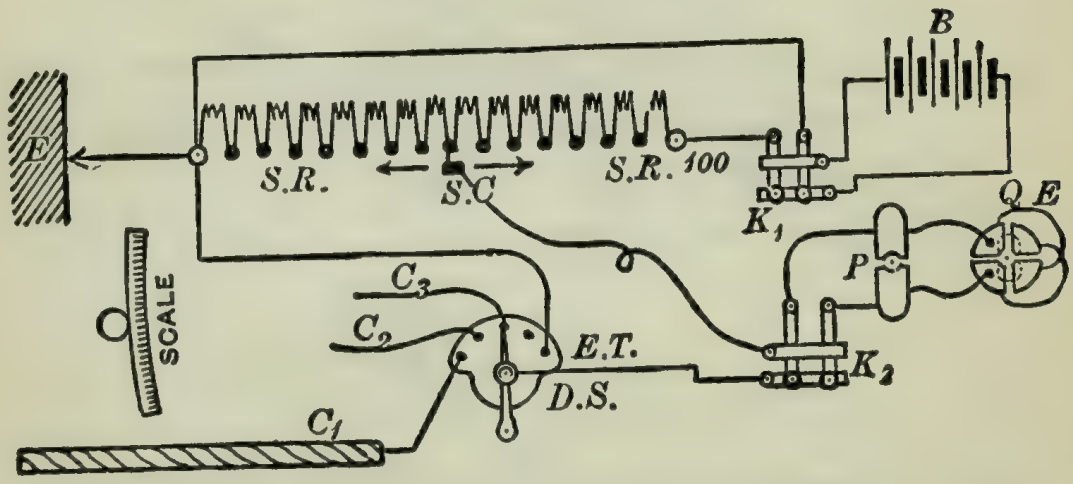
Resistance per Knot.

$$= 9{\cdot}233 \times 632 = 5835 \text{ megohms per knot.}$$

Or working by the table of logs. at end of book.

		logs.	
R =	1·0056	= 0·0023	
d_1 =	306·	= 2·4857	
$\frac{G+s}{s}$ =	7·445	= 0·8719	add logs.
		3·3599	= 2290 = constant.
d_2 =	248·	= 2·3945	subtract logs.
See anti-log.,		0·9654	= 9·233 megohms.
L =	632	= 2·8007	add logs.
See anti-log.,		3·7661	= 5835 megohms per knot.

Method of Testing Highly Insulated Cables with Quadrant Electrometer. By Professors Thomson and Jenkin.



Index to Diagram.

B	represents	Battery (100 to 500 cells) with poles attached to
S R	"	A set of Thomson & Varley's slide resistance coils, by
K_1	"	Reversing key.
S C	"	Sliding contact, by which the desired potential is taken to one electrode of
Q E	"	Thomson's quadrant electrometer by way of
K_2	"	Reversing key, and
P	"	Short circuiting plug for electrometer.
D S	"	Highly insulated distributing switch, bringing
C_1 C_2 C_3	"	Different cables alternately to the other electrode of Q E.
E	"	Earth to which one side of S R and
E T	"	The earth terminal of D S are joined.

Method of taking Test.

1. Charge inside of electrometer to the normal by turning replenisher, and bring spot to zero of scale.

2. Find "inferred zero" or the deflection produced on electrometer scale by a known percentage (generally 10 per cent.) of the full battery power used to charge the cable. This is effected by depressing K_1 (thus sending full battery current through slides S R), and sliding S C to left until it bears on contact No. 10 (or $\frac{1}{10}$ of S R from O or E end); then putting Q E in circuit by pulling out plug P, and depressing K_2, switching D S to E T, when we have one pair of the electrometer quadrants connected to S C and the other pair direct to earth. Then ten times the deflection obtained constitutes the "inferred zero." Apply opposite pole of battery to S R, and take deflection in same way as before. If it is not equal look to insulation of the battery.

3. The inferred zero having been found insert plug P, and relieve keys, K_1 and K_2; shift S C back to 100 on S R, and free D S.

4. Fix down K_1 and K_2, switch D S to terminal connected to cable C_1, at the exact minute; charging it to full potential, 15″ being sufficiently long for a factory core or even a cable of 100 knots. At the end of 15″ take out plug P, which leaves one pair of quadrants directly connected to battery and the other pair to cable. The potential of cable now begins to fall, and spot to travel along scale. Take readings at 1′ 45″ and 2′ 15″ after battery was first applied to cable. The readings have to be subtracted from the inferred zero (they are called P and p), and the logarithms of the differences taken, in order to find the insulation resistance after two minutes electrification.

Note.—Should the potential fall so as to bring the spot beyond the range of the scale, it may easily be brought back by slipping the slide S C down S R towards O or E, and the deflection multiplied by the position of S C gives the full deflection at the time.

Formula—

$$R = \frac{\cdot 4343 \times t}{K \log. \frac{P}{p}}.$$

Where R = the insulation resistance of the cable *per knot* in megohms.

·4343 = the constant for converting log. ε, the Napierian into common logs.

t = time in seconds between the two readings (30″ in this case).

*K = the capacity of cable per knot in microfarads.

P = the difference between the reading at 1′ 45″ and the inferred zero (or potential of cable at that instant).

p = the difference between the reading at 2′ 15″ and the inferred zero (or potential of cable at that instant).

Since $\frac{\cdot 4343 \times t}{K}$ is a constant for the particular cable, we have only to divide it by log. $\frac{P}{p}$ to obtain R.

Example.—Test of Hooper's core at 75° Fah. Where K = ·43 mfds. per knot.

Deflection with $\frac{1}{10}$ battery potential of 100 cells (or S C at contact 10) = 560 divisions.

∴ Inferred zero = 560 × 10 = 5600 divisions.

Time.	Reading.	Diff from Inferred Zero.	Log.	Diff. of Log. or log. $\frac{P}{p}$
1′ 45″	354	5246	3·7198	
2′ 15″	395	5205	3·7164	0·0034

$$\text{Constant} = \frac{\cdot 4343 \times 30}{\cdot 43} = 30\cdot 3$$

$$R = \frac{30\cdot 3}{\cdot 0034} = 8911 \text{ megs. per knot.}$$

* K is found for the cable being tested, see p. 116.

Electrometer Test—(*Continued*).

The advantages of this mode of testing, compared with the common galvanometer, are increased delicacy and accuracy; for the delicacy may be increased indefinitely by increasing the E M F of the battery, the sensitiveness of the instrument, and the time, *t*, between readings. The absence of any magnet in the electrometer allows the test to be made while machinery is in motion. Currents, which from various causes are induced in the cable giving irregular deflections on a galvanometer, do not affect the electrometer. Short coils of high insulation resistance, which would show no sensible leakage on a galvanometer, are easily tested by this method; and last, not least, several coils or cables can be tested at one time by having them connected on to the distributing switch, D S, as shown, and charging as well as observing their fall of potential at suitable times (three cables can easily be done at one time), thus saving much time and labour. Many thousands of miles of core and cable have been tested by the authors with the above system, and they can thoroughly recommend it.

CAPACITY TESTS OF CABLES.

Thomson's Method (See fig., p. 116).

In testing short lengths of core, say one-knot pieces, in the guttapercha factory, it saves calculation; if $R_2 = 5000$ ohms and $K_1 = \cdot 5$ microfarad, then the capacity can be read off directly to four places of decimals from R_1. If testing three to four knot-lengths, R_2 may conveniently be made equal to 1000 ohms, and $K_1 = 1$ microfarad.

In testing long submerged cables of, say, 1000 knots or more, R_2 may be = 1000 ohms, and $K_1 = 100$ microfarads. K_1 being composed of the large signalling condensers used at cable stations with siphon recorder or mirror. K_1 is first carefully tested and adjusted by comparing it with a standard condenser. If earth-currents exist, free cable by a special key immediately before discharging condenser K_1 through galvanometer, taking the mean of several + and − readings of R_1 and R_2.

The capacity of a cable per knot is the total capacity divided by the length in knots.

Note.—In order to get uniform capacity tests by this method, it is well to adopt some fixed time of charging and mixing, because condensers of different materials, such as a standard shellac-mica condenser with a condenser of paraffined tinfoil, or a condenser and a cable, have different rates of absorption.

Dr. Muirhead recommends, when comparing small capacities, say a standard $\frac{1}{3}$ to 1 microfarad shellac-mica condenser with a 10 to 20 microfarads paraffin-tinfoil one, a charge of 15 seconds, and a mix of 4 seconds. With a long cable of 1000 knots the authors have found a charge of 5 minutes, with 10 seconds for mixing, to do very well.

Example—Gibraltar-Malta Cable, tested at Malta by A. Jamieson. Length = 1120 knots; Insulation Resistance, 5th minute = 1490 megohms per knot; Total Copper Resistance = 11,293, or per knot = 10·083 ohms. $K_1 = 100$ microfarads of signalling condensers, carefully tested in portions of about 20 mfds., and then finally adjusted to a total of 100 mfds. by comparing with a 1 mfd. standard condenser.

K_2 = total capacity of cable to be found; R_2 = 1000 ohms. fixed resistance; R_1 = 3846 ohms. (being a mean of 5 alternate tests with 10 cells, copper (+) and zinc (−) to cable, in order to eliminate the error arising from earth or cable currents). A very sensitive astatic mirror galvanometer was used. The cable and the 100 mfds. condenser were charged simultaneously for five minutes, then allowed to *mix* for ten seconds, both being earthed for a few minutes between each (+) and (−) test, in order to discharge them.

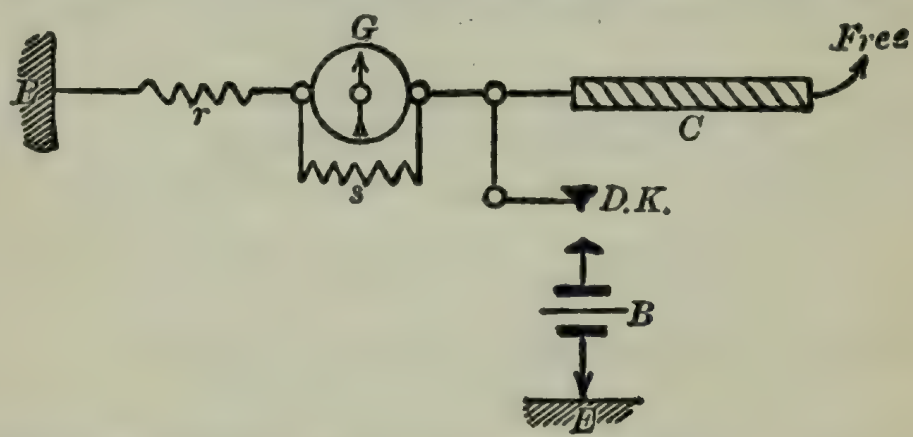
$$\text{By formula, } K_2 = \frac{R_1}{R_2} K_1 = \frac{3846}{1000} 100 = 384{\cdot}6 \text{ mfds.}$$

$$\therefore \text{ Capacity per knot}$$

$$= \frac{\text{Total Capacity}}{\text{Length in Knots}} = \frac{384{\cdot}6}{1120} = 0{\cdot}3434 \text{ mfd.}$$

A similar test from Gibraltar end gave 0·343 microfarad per knot.

By Loss of Charge (*Sir William Siemens*).—This method is suitable, either for long or short cables, but is less accurate than Sir W. Thomson's (see pp. 116 and 154).



Where C represents the cable or condenser.
D K " discharge key.
G " astatic galvanometer.
r " high resistance box in megohms.
B " battery.
E " earth.

Data for Formula:—

Let K = Total capacity of cable or condenser in microfarads.

r = High resistance as in the fig. including G or $\frac{Gs}{G+s}$ in megohms.

R = Absolute insulation resistance in megohms of cable after T minutes electrification (for a long cable T = 30′).

P = Full potential or *the first* deflection through r observed on G after charging cable for T minutes.

p = Potential to which conductor falls in time t seconds after disconnecting battery, or *the second* deflection through r observed on G after t seconds from taking P.

Then $$K = \frac{\cdot 4343 \times t}{\frac{rR}{r+R} \cdot \log. \frac{P}{p}} \text{ microfarads.}$$

If a quadrant Electrometer be used instead of G, then r may be dispensed with,

and $$K = \frac{\cdot 4343 \times t}{R \cdot \log. \frac{P}{p}} \text{ microfarads.*}$$

In the above tests all connections and instruments must be well insulated.

* See pp. 151–153. Insulation Test by Electrometer.

SLOW DISCHARGE METHOD (*Sir W. Siemens*).—Charge the condenser fully, then discharge it through the galvanometer. Note the deflection, P, potential. Recharge the condenser fully, and allow it to discharge through a resistance, R, megohms, for time, t, seconds, then discharge it through the galvanometer. Note the deflection, p, potential.

Then

$$K = \frac{t}{R \log._{\varepsilon} \frac{P}{p}} = \frac{\cdot 4343 \times t}{R \log. \frac{P}{p}} \text{ microfarads}$$

It is better to make p as nearly as possible equal to $\frac{P}{3}$. If R is adjustable, make it as high as is convenient. Log. ε is the naperian log.

FAULTS IN SUBMERGED CABLES.

By A. Jamieson.

Protection of Conductor.—Whenever a fault appears in a cable, which does not entirely prevent telegraphic communication, the signalling batteries at each end should be reduced in power to a minimum, and a small "protecting battery" attached to the end of cable nearest fault as a T piece, with its (−) pole fixed to the junction between cable and signalling condensers, and its (+) pole to earth through a high resistance (say 10,000 ohms). This causes a negative current to flow constantly to the fault, which keeps it clean, and prevents the conductor being eaten away at the fault by the signalling currents.

Localising Faults.—The "breaking down" of a high resistance, or small fault, with strong reversing currents should only be resorted to after every other method of localising it has failed, as such treatment has a great tendency to develop other faults, especially if the original fault be at a considerable distance. In all cases, when localising faults, use as small a battery power as practicable, just sufficient to enable the resistance to or of the fault to be determined with accuracy.

Polarisation.—Never depend entirely upon results obtained with the (+) pole of the battery to cable, or with observations taken after the resistance of the fault has begun to increase with the (−) pole to cable, since a (+) current has the power of depositing copper salts at, and thereby increasing the resistance of, the fault, while the (−) current reduces and throws off these salts, but immediately thereafter it begins

to generate hydrogen, which also clings to, polarises, and increases the resistance of, the fault. It is therefore best in all cases where the fault makes earth, to charge first with a (+) current, and then to take observations with a (−) current; noting, as most correct, that obtained immediately before a sudden increase in resistance takes place. The testing battery should be very constant, well insulated, and of low resistance, such as De la Rue's chloride of silver cells, or good Daniell's, with large well amalgamated zinc plates.

Galvanometer.—In all tests, such as Varley's Loop and Blavier's, where it is advisable to balance to earth or cable current zero, a sensitive *dead beat* mirror galvanometer is preferable to an equally, or even more sensitive astatic galvanometer.

Resistance.—In all cases where the resistance of a fault bears an appreciable ratio to the *absolute* insulation res. of the cable, it is advisable to make correction for the apparent position of the same by taking into account the position and resistance of the "natural resultant fault." In single cables, this "natural resultant fault" has generally to be assumed to be at the centre of the cable, and is equal to the absolute insulation res.; but in duplicate cables, or where a loop test can be applied, the exact position and value of the natural resultant fault should be frequently obtained by a Varley's Loop and ordinary insulation tests. In dealing with long cables and faults of, say, over 100 ohms resistance, this correction is absolutely necessary before the true position of the fault can be arrived at with accuracy. See Index for corrections on Loop Tests.

COMPLETE BREAK.—When the cable is severed and the fault itself offers no resistance, the distance from the test end to the fault is,

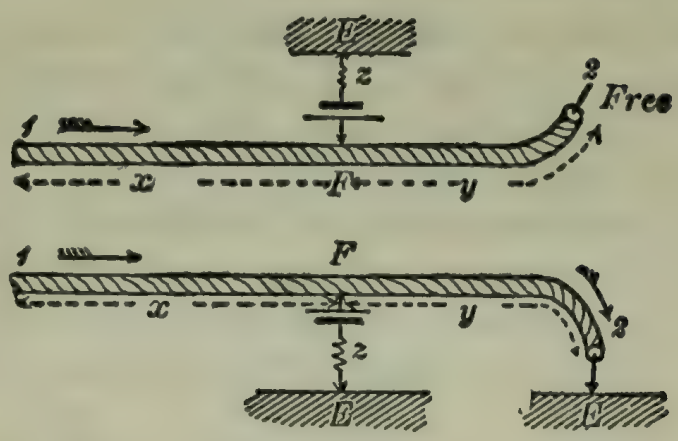
$$\frac{R}{r_k} \quad . \quad . \quad . \quad . \quad . \quad \text{knots.}$$

Where R = measured resistance from one end.
r_k = resistance of the cable per knot.

This is frequently the case when the core is sheathed with Clifford's brass tape, applied to cables as a protection against toredo boring.

BLAVIER'S FORMULA.

When the cable is submerged, and only one end is to be had, its resistance, R, is measured when the further end is insulated, and the resistance, r, when it is to earth. See fig. p. 162. This can, of course, only be done when the fault is not so great as to entirely prevent communication, or when by pre-arrangement, the electrician at the distant station knows when to put his end to earth, and when to insulate it. These tests are usually made by Wheatstone bridge. See page 141. But sometimes by direct deflection. See page 143.



Let res. from end 1 with end 2 free = R
,, ,, ,, ,, ,, earthed = r
,, from end 1 to fault F = x
,, ,, ,, 2 ,, ,, = y
,, of fault to earth = z
copper res. of line when good = l

(1) . . . $l = x + y$ . . . ∴ (4) . . . $x = l - y$
(2) . . . $R = x + z$ . . . . ∴ (5) . . . $x = R - z$
(3) . . . $r = x + \frac{yz}{y+z}$ . . . ∴ (6) . . . $x = r - \frac{yz}{y+z}$

Now, from equations (4) and (5), we see that,—

$$l - y = R - z$$

$$\text{or} \ldots\ldots z = R - l + y,$$

From equations (4) and (6)

$$l - y = r - \frac{y(R - l + y)}{R - l + 2y}$$

Multiply both sides of the equation by $(R - l + 2y)$ we get

$$y^2 - 2y(l - r) = Rl - l^2 - Rr + lr,$$

Working out the quadratic equation,

$$y = l - r + \sqrt{r^2 - Rr + lR - lr}$$

$$= l - r + \sqrt{(R - r)(l - r)}, \text{ ohms} \ldots (7)$$

From equation (4), and substituting value of y in (7),

$$x = l - y = r - \sqrt{(R-r)(l-r)}, \text{ohms}. \quad (8)$$

From equations (4) (5) (7),

$$z = R - l + y = R - r + \sqrt{(R-r)(l-r)}, \text{ ohms} \ldots \quad (9)$$

We have now only to divide x or y by the resistances per knot of the cable in order to get the number of knots the fault, F, is from station 1 or station 2.

Hockin's Correction for the true total C R, (l) should be applied in the case of long cables or those of low insulation resistance,—

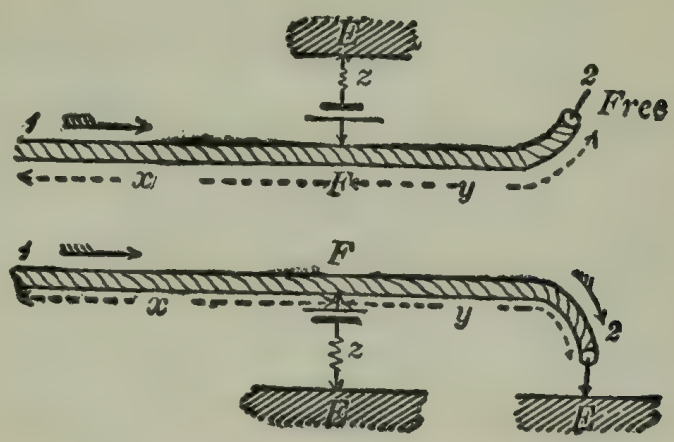
$$\text{viz., } \ldots \; l = r'\left(1 + \tfrac{1}{3}\frac{r'}{R'}\right)$$

Where r' = observed C R in ohms, when line perfect corrected for temp.
R' = observed I R in megohms, when line perfect, corrected for temp.

Instructions should be issued to cable stations that upon a fault breaking out which prevents signalling, the end should be freed and earthed alternately at certain periods at each end—say, 5 minutes free and 5 minutes earth for 1 hour, beginning at a fixed hour with end 1, and the same for the next hour with end 2. In this way Blavier's test may be applied at each end and position of fault calculated if conductor is not severed.

The tests so obtained may also be used in the following modification of Blavier's test by Jamieson :—

To find position of a fault, if conductor is not severed,



Let

$$l = x + y \therefore x = l - y \quad . \; . \; . \; . \; (1)$$

When end 2 free,

$$R_1 = x + z \therefore z = R_1 - x \quad . \; . \; . \; . \; (2)$$

When end 1 free,

$$R_2 = y + z \therefore z = R_2 - y \quad . \; . \; . \; . \; (3)$$

When end 2 earthed,

$$r_1 = x + \frac{yz}{y+z} \quad . \; . \; . \; . \; . \; . \; . \; . \; (4)$$

When end 1 earthed,

$$r_2 = y + \frac{xz}{x+z} \quad . \; . \; . \; . \; . \; . \; . \; . \; (5)$$

NOTE.—The Result, R_1 and r_1 are obtained at end 1.,
and " " R_2 " r_2 " " " 2.

Substitute value of x from (1) and z from (3) in equation (4),

$$i.e., r_1 = x + \frac{yz}{y+z} = l - y + \frac{y(R_2 - y)}{R_2}$$

$$r_1 R_2 = R_2 l - y^2$$

$$y^2 = R_2 l - R_2 r_1$$

$$y = \sqrt{R_2 (l - r_1)} \quad . \quad . \quad \text{ohms.}$$

In same way $x = \sqrt{R_1 (l - r_2)}$. . . ohms.

Simple Overlap Formula.

From equations (1) (2) (3) from last tests, by two measurements with distant ends free,

$$\left.\begin{aligned} x &= \frac{l + R_1 - R_2}{2} \\ y &= \frac{l + R_2 - R_1}{2} \\ z &= \frac{R_1 + R_2 - l}{2} \end{aligned}\right\}$$

For Anderson and Kennelley's Overlap Test, see *The Electrician*, July 17, 1885.

Also from equations (1) (4) and (5), by two measurements with distant ends earthed,

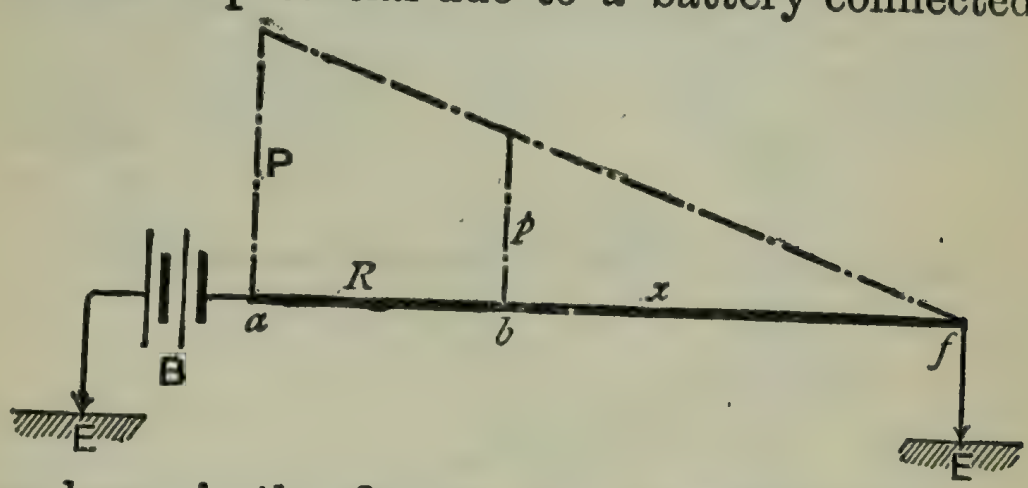
$$x = \frac{r_1 (l - r_2)}{r_1 - r_2} \left\{ 1 - \sqrt{\frac{r_2 (l - r_1)}{r_1 (l - r_2)}} \right\}$$

$$y = \frac{r_2 (l - r_1)}{r_2 - r_1} \left\{ 1 - \sqrt{\frac{r_1 (l - r_2)}{r_2 (l - r_1)}} \right\}$$

Taking the mean of the above results, we have, as before, only to divide x or y by the copper resistance per knot to get the distance in knots of the fault from station 1 or 2.

Blavier's method, as above, and modification is very exact in the case of a short highly insulated cable (under 500 knots), containing a fault of less than 100 ohms to earth. It cannot be solely relied on to indicate exactly the position of a fault in a long, or one with low insulation resistance, neither should the fault resistance to earth be much over 100 ohms. The fall of potential method or a combination of it and a Wheatstone bridge test, see p. 167, should, in such cases, be applied as a check on test, p. 174, and where there are two cables, loop tests.

By Fall of Potential.—When the fault is "dead earth," or offers no resistance in itself, the fall of potential due to a battery connected,



as shown in the figure, will be regular along the cable from its end, b, to zero at the fault, f. Let P and p be the potentials at the points a and b, separated by the resistance, R, which is known.

Then, $\quad P : p :: R + x : x$, and

$$x = R \frac{p}{P - p}$$

Where x = resistance of the cable, bf, to the fault. P and p are easily taken by "null method," p. 90.

Clark's Method.—When the cable does not make "dead earth" the potential will not be zero at the fault, but will have a value dependent on the resistance of the fault. This value will, however, be equal to the potential at the far end of the cable if that is insulated, and knowing it we can find the position of the fault. In the

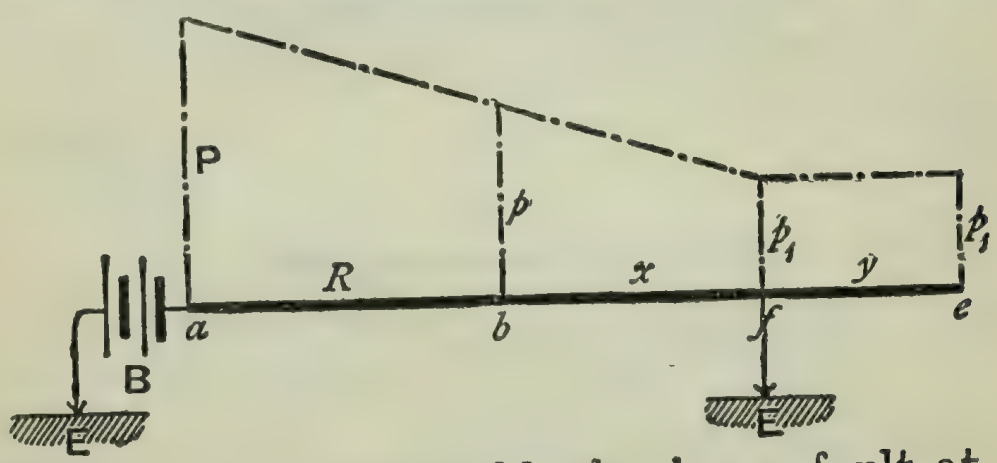


figure let $b\,e$ be the cable, having a fault at f, and its end, e, insulated. Let R be a resistance between the battery, B (of very low resistance), and the end, b, of the cable.

Then $\quad P - p_1 : p - p_1 :: R + x : x$

$$\therefore\ x\,(P - p_1) = (R + x)\,(p - p_1),$$

$$x = R\,\frac{p - p_1}{P - p}$$

To determine the relative values of P, p and p_1 they should be compared by the slide, "null method" against a standard E.M.F., see p. 90; such as given by Clark's or De La Rue's cells. The observations of p and p_1 should be taken at same time, and due allowance made for the earth or fault current potential, which is taken in same way as p and p_1 before and after each set of readings.

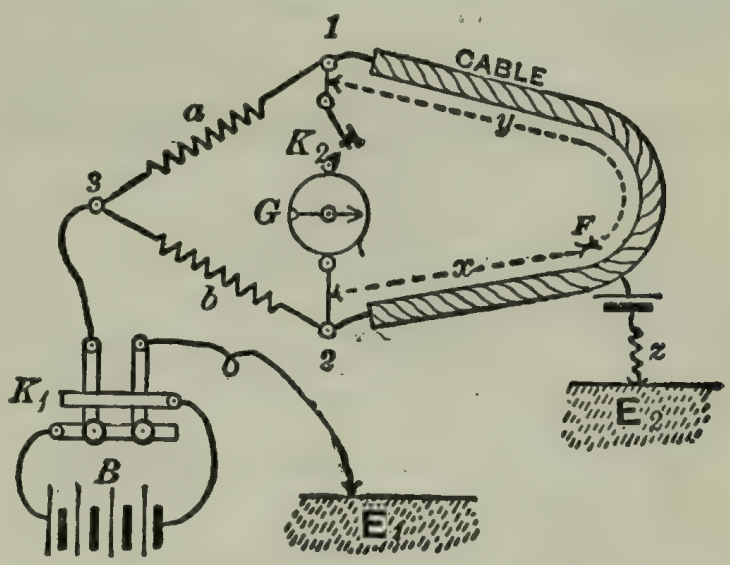
If instead of finding P by introducing res., R, we apply the bridge test, p. 141, and get by it, a

res., R, which balances, $x+z$, the res. to and of the fault, at the same time measuring p and p_1 by slides as before.

Then $$x = R\left(\frac{p - p_1}{p}\right)$$

This method yields excellent results, and is to be preferred to the Varley loop test, if the fault is near the testing station and the cables long. The plans of testing at ends, *b*, and *e*, should be reversed and the results compared.

THE LOOP TEST.—When a faulty cable is in the tanks, so that both ends can be got at, or when it is submerged and a second wire or cable can be joined to it at the far end, the *loop test* is the best. It is independent of the resistance of the fault, and there is therefore less need to clean and depolarise the fault than in other tests.



Murray's Method.—(1.) Connect up as in fig.
Where a and b = Sides of bridge.
,, F = Position of fault.
,, z = Resistance of fault to earth, E_2.
,, x and y = Resistances to the fault.
,, l = Res. of looped conductor.

(2.) Apply + or − pole of battery by key, K_1, balancing to the "false or cable current zero."

Formula:—By Wheatstone bridge,

$$ax = by,$$

and $$l = x + y \quad . \quad . \quad \therefore y = l - x,$$

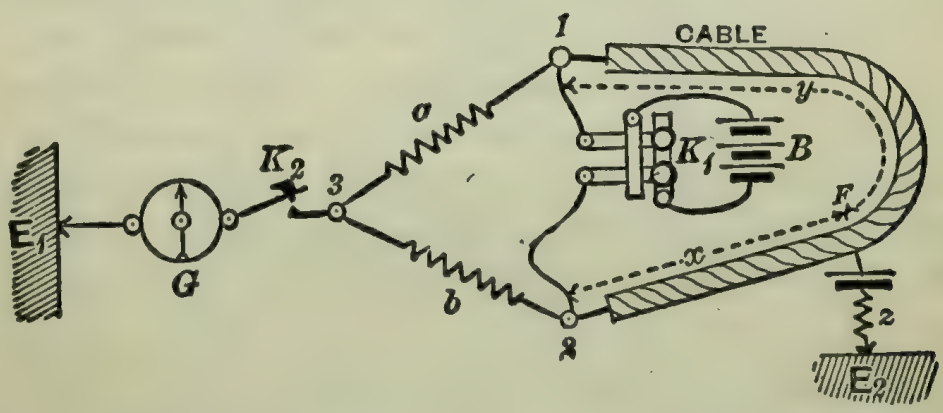
$$\therefore x = \frac{b}{a+b} l$$

$$y = \frac{a}{a+b} l$$

The distance in knots from end 2 = $x \div$ res. per knot.

" " " 1 = $y \div$ "

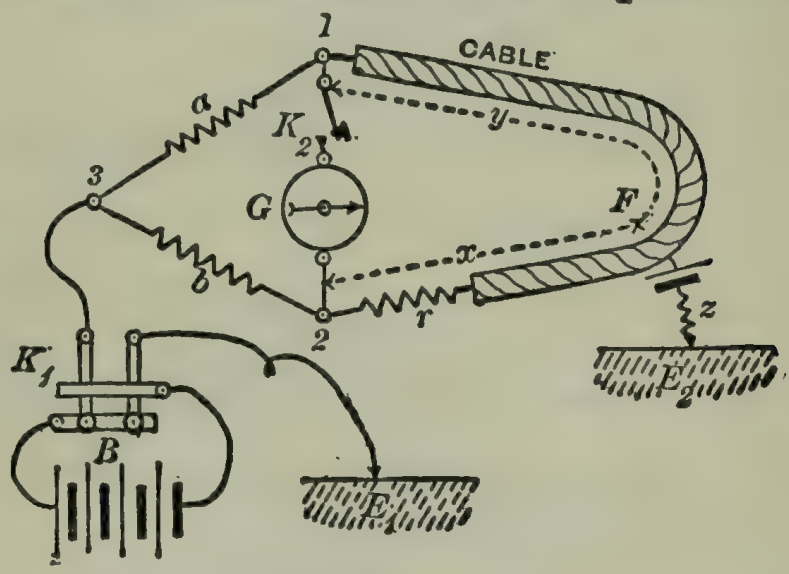
A useful modification of the above test is shown below. In the case of a few miles of cable on board ship or in a factory, it is more accurate than the foregoing. Here the battery, B, must be very well insulated and of low resistance.



The method of taking test and formula are identical with the former. It is always well to reverse ends of cable to points 1 and 2 of bridge, and take the mean of both results.

Taking the Test.—(1.) Close K_2, and observe "false zero" due to battery created by fault and earth-currents.

Best Conditions.—Kempe recommends that the battery power be such as will give a deflection when *b* is a unit or less out of adjustment; that *a* should be as high as is necessary to give sufficient range of adjustment in *b*; and that the galvanometer resistance should not be more than five times the resistance of the looped cables.



Varley's Method.—Connect up as shown in the diagram. The only difference between this and Murray's test is, that a resistance, *r*, is introduced between one end of the cable and terminal, 2, of the bridge, see p. 168.

Taking the Test.—(1.) Close key, K_2, observe deflection due to fault, F, of cable or earth-current, *i.e.*, note "false zero."

(2.) Release K_2, and thereafter apply + or − pole of battery, B, by key, K_1, and depress K_2. *Be sure to balance to the false zero just obtained,* then the best value of *r* will be obtained when

the resistance of the fault, z, is a minimum, *i.e.*, when it is cleaned by the (−) pole of the battery and just before it begins to polarise.

(3.) The value, l, or copper res. of looped cables is sometimes assumed from previous tests taken when cables perfect, to be the sum of the C R^s of the two cables, or it may now be found by an ordinary bridge test. These two results will not be the same.

In this test $x = r +$ res. to fault from end 2.
$y =$ resistance to fault from end 1.
$l =$ res. of looped conductor.
a and $b =$ the ratios of bridge.

By Wheatstone bridge formula,

(1.) . . $ax = by$ . . $\therefore y = x\frac{a}{b}$

(2.) . . $l = x + y - r$ $\therefore x = l - y + r.$

Substitute in equation (1.) the value of x in (2.),

we get $$y = \frac{a}{a+b}(l + r)$$

If the ratios of bridge are equal, *i.e.*, $a = b$, then

$$y = \frac{l+r}{2} = \text{distance in ohms of fault from end 1.}$$

$$\therefore \frac{l-r}{2} = \text{dis. in ohms of fault from other end.}$$

EXAMPLE (*Jamieson*). — Suez-Aden cables looped at Suez.

Results obtained with even bridge, or $a = b$,

Mean of CR^s of loop, $l = 29575$ ohms } corrected
,, balancing res. $r = 1470$,, } for temp.

∴ Distance of fault from Aden in ohms

$$= \frac{l - r}{2} = \frac{29575 - 1470}{2} = 14053.$$

Note.—In finding the position of a fault by loop tests, depend more on results obtained at the station furthest from the fault, as the true position of the fault, and the "natural resultant fault" of the cable, are closer together when viewed from that end. When these tests are carefully taken with l, the C R of looped cable, and r, the balancing resistance (both obtained as nearly as possible at the same time, with — pole of battery), and corrected for temperature of coils.

The above formula, $\frac{l - r}{2}$, will generally give a better result than taking l as the C R of cables looped when perfect, and applying the following corrections for tests taken from end next fault, for the reason of the difficulty of knowing the correct value and position of the natural resultant fault.

The *Natural Resultant Fault* is the centre of leakage of the cables insulation resistance, in its normal condition before the fault sought for occurs, and is obtained by a loop test in the ordinary way.

Hockin's Correction for the true total C R of l, with cables looped, may be applied in the case of long cables, or those with low insulation resistance, viz.:—

$$l = r' \left(1 + \frac{1}{12} \frac{r'}{R'}\right)$$

where r' = observed C R in ohms of looped cables corrected for temperature.
R' = observed I R in megohms of looped cables corrected.

Best Conditions.—Kempe recommends that r should be as high as possible, but not so high that $r + y$ exceeds $G + x$; r being adjustable to fractions of a unit, if it has to be of low value. a must neither be greater than $br + z + x$, nor

less than x. br is the resistance of the battery, z the fault, and G that of the galvanometer.

Correction for Varley's Loop (*Kempe*).—The difference in ohms between the apparent position of fault and the true position

$$= \frac{I}{P-I}(\beta - \alpha), \text{ ohms.}$$

Where P = the absolute insulation res. in ohms before fault occurred.

I = the absolute insulation res. in ohms with fault at time of test.

β = apparent distance in ohms of fault by loop test from

α = apparent distance in ohms of natural resultant fault obtained before fault broke out.

Combined Resistance and Discharge Test when Cable Broken (*Kempe*).

1. Observe by the Wheatstone bridge test (see fig., p. 142), the res., R, which balances x, the res. to the fault plus, z, the res. of the fault.

2. Immediately on procuring a balance, discharge end of cable (relieving it from point 2 of bridge), through an astatic galvanometer, noting deflection, d_1.

3. Compare this discharge deflection, d_1, with that of d_2; the discharge obtained from a condenser of known capacity, K, charged similarly, and with the same battery as the cable, in case 1.

Let k = the capacity per ohm of res. of cable.

R_1 = the combined res. of a, b, R, and G (see fig., p. 142).

R = $x+z$ (see fig., p. 162).

Then the distance to fault in ohms,

$$x = R - \sqrt[3]{R^3 - \frac{3\,d_1\,K}{d_2\,k}(R_1 + R)\,R}\,*$$

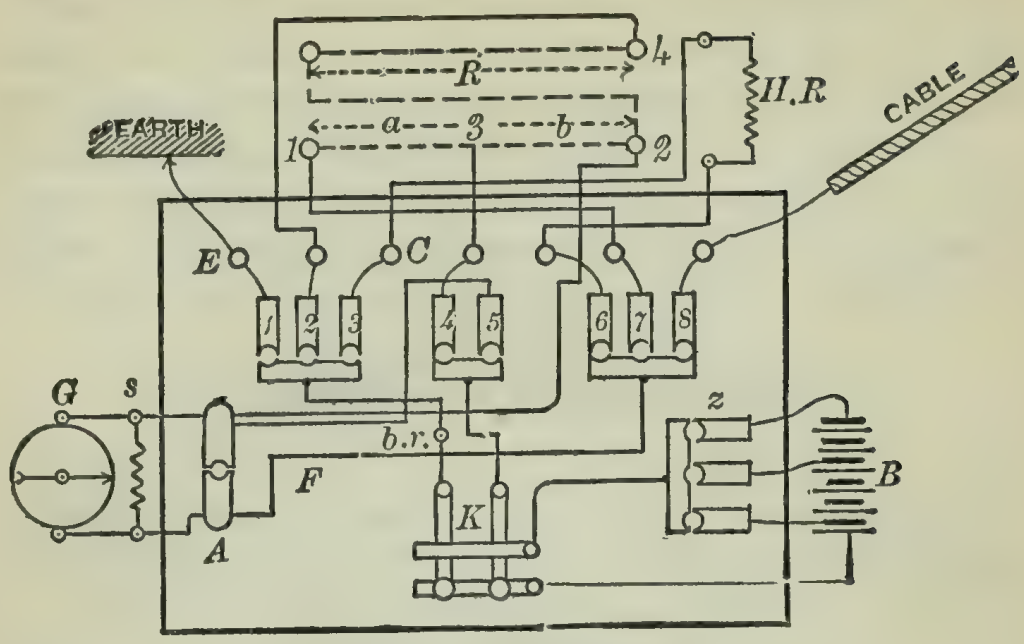
The great merit of this method is, that the two first measurements for R and d_1 can be taken almost simultaneously.

Total Discontinuity.—When the conductor of a cable is severed but the core remains intact, charge the cable with a battery, then discharge it through a galvanometer. Compare this with the discharge of the same battery from a standard condenser, and calculate the capacity of the cable to the break (see p. 115). Or obtain capacity of cable to break of conductor by Thomson's method (see p. 116). This divided by the known capacity per knot gives the distance to the break in knots.

* For a complete solution with examples of Kempe's methods of localising earth faults in cables, see his Handbook of Electrical Testing, Third Edition, pp. 403–412.

SAUNDERS' TESTING BOARD.

This arrangement is very handy, and can be made thoroughly well insulated in all climates and states of the atmosphere, if proper precautions are taken, such as running the connections in grooves formed in the ebonite base, and filling them up with the best insulating shellac, the same as Dr. Muirhead uses for his standard condensers.



Index to Diagram.

Where G represents Galvanometer.

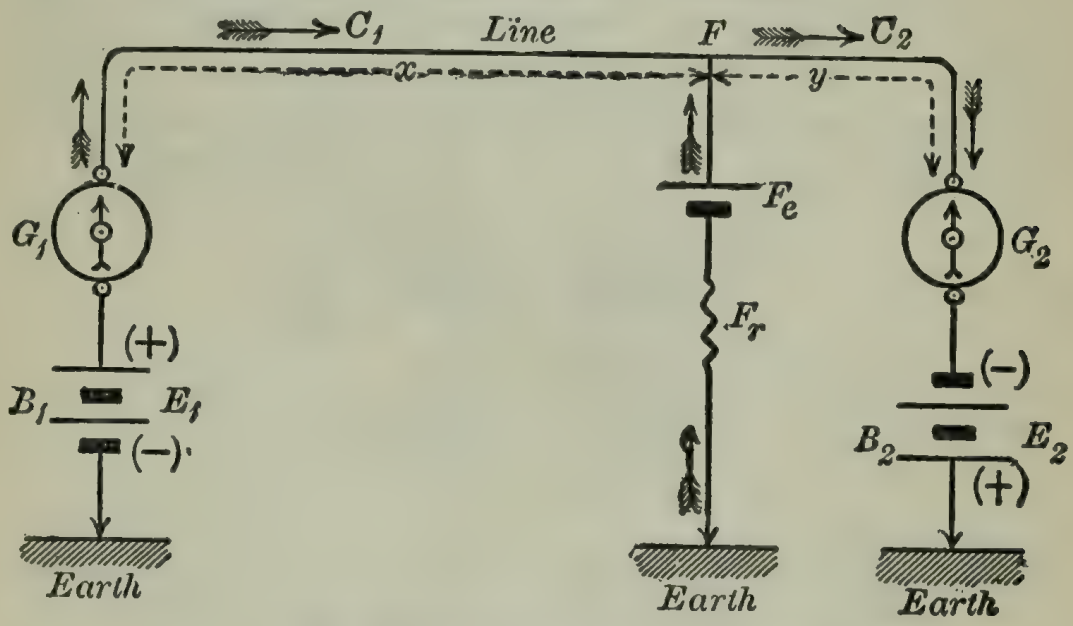
s	"	" shunt.
K	"	Key.
B	"	Battery.
b r	"	" resistance plug, may be introduced between K and E.
H R	"	High resistance (megohms).
1,2,3,4,	"	Positions of bridge (see figs. of bridge tests).
1, 2, 3 . . 8	"	Commutators.
z	"	Battery commutator.

Arrangements for Different Tests.

For Constant, plugs in 3, 5, 6 (see p. 148).
" Insulation, plugs in 1, 5, 8 (see p. 146).
" Copper resistance, plugs in 1, 2, 4, 7, 8 (see p. 141).
" Varley's loop, plugs in 1, 4, 7, 8, and other end of cable to **4** (see p. 170).
" Metallic circuit, plugs in 2, 4, 7, 8, and other end of cable to **4** (see p. 96).
" Murray's loop, plugs in 1, 4, 7, 8. Shift **2** to **4**, and join other end of cable to **4** (see p. 168).
" Internal resistance of battery, plugs in 2, 7, 5. Small shunt between terminals of galvanometer (see fig., p. 110).
" Murray's loop with G and B reversed, plugs in 2, 4, 7, 8. Free F, and put A to E and other end of cable to **4** (see fig., p. 169).

DUPLEX PARTIAL EARTH TEST (*Ayrton & Perry's method*).—When a loop test cannot be employed, and when Blavier's test (p. 161), is unreliable, this test may be applied with good results, since:—1. It is independent of changes of resistance of the fault. 2. It is independent of any E.M.F. in the fault. 3. It can be carried out with ordinary galvanometers, &c.

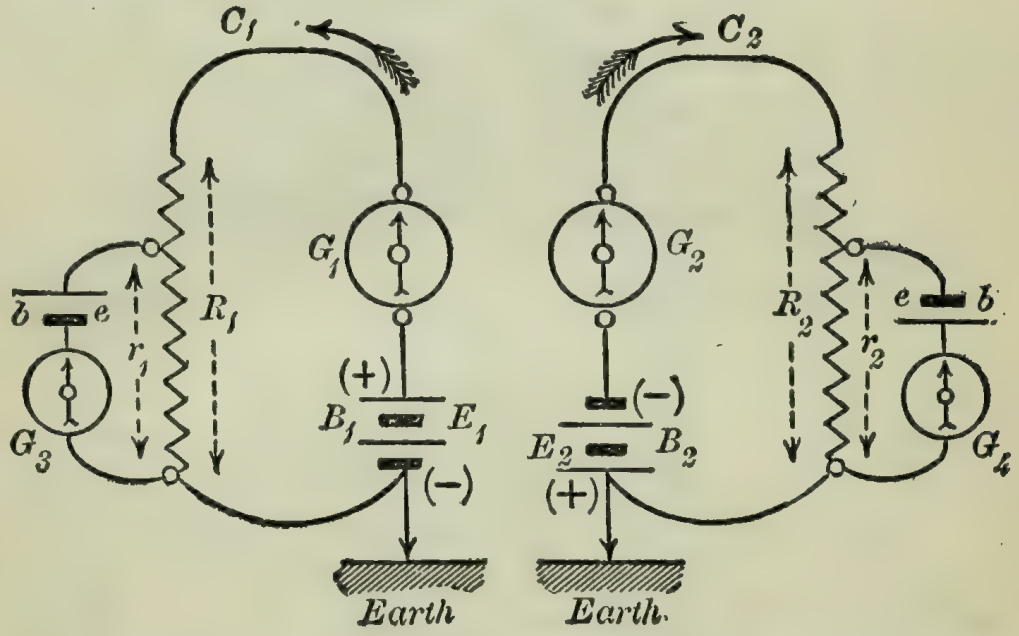
Taking the Test.—1. Connect galvanometers and batteries, G_1, B_1, to one end of cable or line, and, G_2, B_2, to the other end, as shown by fig. Let the fault be at F, or a distance $= x$ ohms from G_1, and y ohms from G_2.



DUPLEX PARTIAL EARTH TEST.

2. Whilst a current, C_1, is flowing through G_1, and C_2, through, G_2, observe the deflections, or bring each of their needles or spots of light *simultaneously* to zero by simply turning their controlling magnets. The precise *instant* when the two deflections are to be observed, or when each of the needles or spots are to be brought to zero may be pre-arranged between the electricians at each end, if signalling can be effected through the line; or if a second line should be

available which is at the same time too faulty for loop-tests, the signal may be sent through it or in the case of a cable across a river a visible signal made on one bank can be seen at the other.



2. Disconnect, G_1, G_2, from the cable, and insert resistances, R_1, R_2, as shown by the above figures, until, C_1, C_2, before observed, are reproduced, or until the needle or spot returns to zero without altering the position of the controlling magnets.

3. Attach Clark cells, *b*, *b*, or other cells of known and equal *e.m.f.*, *e*, to points on the resistances, R_1, and R_2, until no deflection is observed on the detectors or galvanometers, G_3, and G_4. Let the resistances between these points be respectively, r, and r_2.

Now if, l, = the resistance of the line between G_1, and G_2, when no fault existed,

$$x = \frac{r_2 R_1 + r_1 (R_2 - l)}{r_2 - r_1}, \text{ ohms.}$$

$$y = \frac{r_2 (l - R_1) - r_1 R_2}{r_2 - r_1}.$$

For let E_1, E_2 = the E.M.F's of the batteries,
B_1, B_2 = the resistances ,,
C_1, C_2 = the currents through the portions of the line x and y.

From the *first* test (made simultaneously at the two ends of the line), by Kirchoff's second law we have—

$$E_1 + E_2 = C_1 (x + G_1 + B_1) + C_2 (y + G_2 + B_2).$$

The fault, F, may have a variable resistance, F_r, and a variable E.M.F., F_e; also a current may be flowing through the fault, but the above equation contains *none* of these unknown quantities. From the *second* and *third* tests we find by Ohm's law

$$C_1 = \frac{E_1}{R_1 + G_1 + B_1}.$$

$$C_2 = \frac{E_2}{R_2 + G_2 + B_2}.$$

$$\frac{E_1}{e} = \frac{R_1 + G_1 + B_1}{r_1}.$$

$$\frac{E_2}{e} = \frac{R_2 + G_2 + B_2}{r_2}.$$

Therefore, eliminating C_1, C_2, E_1 and E_2,

We have $$\frac{x - R_1}{r_1} = \frac{R_2 - y}{r_2}.$$

But $$y = l - x.$$

$$\therefore (r_2 - r_1) x = r_2 R_1 + r_1 R_2 - r_1 l.$$

Hence $$x = \frac{r_2 R_1 + r_1 (R_2 - l)}{r_2 - r_1}.$$

And $$y = \frac{r_2 (l - R_1) - r_1 R_2}{r_2 - r_1}$$

THE SILVERTOWN PORTABLE TESTING SET FOR ELECTRIC LIGHT CABLES AND WIRES, &c.

Conductor Resistance.—The apparatus consists of:—

a and *b* for Wheatstone bridge arms in ohms.
R and R „ resistances (dial pattern) in ohms.
G „ galvanometer (horizontal needle pattern).
K „ key to bring galvanometer into circuit.

Instructions.—1. Place the testing set on a level table or stand, and in such a position that the galvanometer needle points to zero.

2. Connect flexible (+) and (—) battery wires (1 to 10 cells Leclanché or Daniell according as the resistance, *x*, is small or large) to the box, by inserting the plugs connected to these wires into bridge holes, C and Z, respectively.

3. Connect the conductor, *x*, or circuit to be measured to the bridge terminals, **2** and **4**.

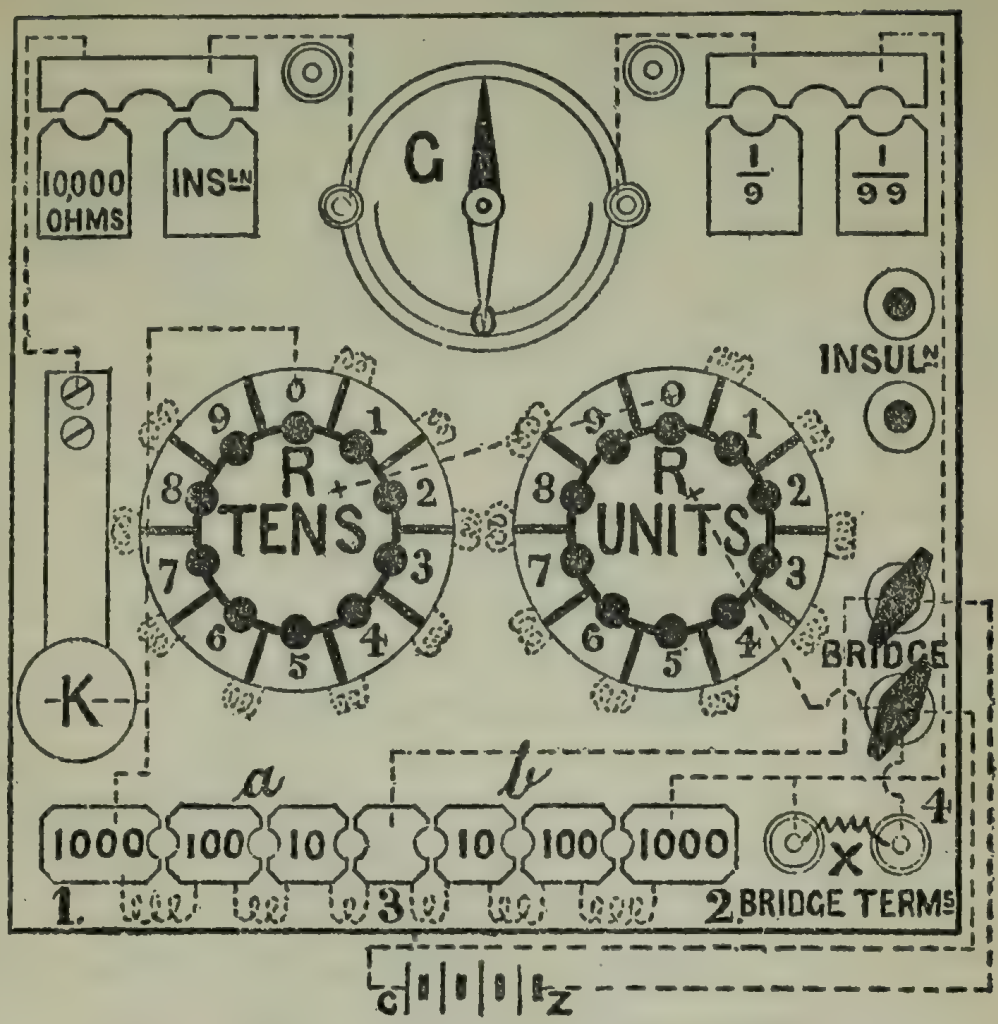
The principle upon which the conductor resistance is obtained, is precisely the same as that of the ordinary Wheatstone bridge test.

Consequently, the known resistances, *a*, *b*, and R, have first to be unplugged until (on depressing the key, K), there is no perceptible deflection of the galvanometer—*i.e*, until there is no appreciable difference of electrical pressure between the points **1** and **2**.

These conditions are *only* obtained when

$$a \times x = b \times R.$$

Or,—*The product of the resistances in the opposite sides of the bridge must be equal to one another.*



PLAN OF APPARATUS FOR COPPER RESISTANCE.

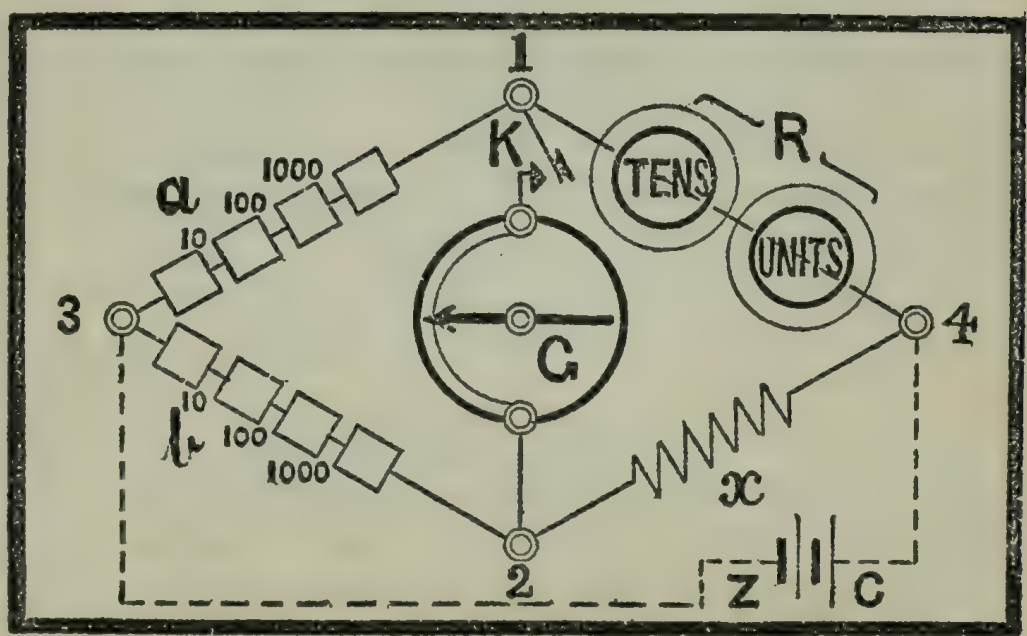


DIAGRAM OF CONNECTIONS FOR COPPER RESISTANCE.

We may best obtain this result according as the resistance, x, is *large*, *medium*, or *small*, by varying the ratio of a to b, according to the following table:—

Resistance of x in Ohms.	Left Arm, a.	Right Arm, b.	
900 to 9,900	10	1,000	Multiply R by 100
90 to 900	10	100	" " 10
9 to 90	10	10	$x = R$
·9 to 9	100	10	Divide R by 10
·01 to ·9	1,000	10	" " 100

When adjusting the dial resistances the galvanometer deflection will be to the one side if R is higher than required, and to the other side if less. This deflection becomes less and less the nearer R is to the required value. It will be found handy to paste a piece of paper on the galvanometer glass marked "more" on one side and "less" on the other to indicate when to increase or diminish, R.

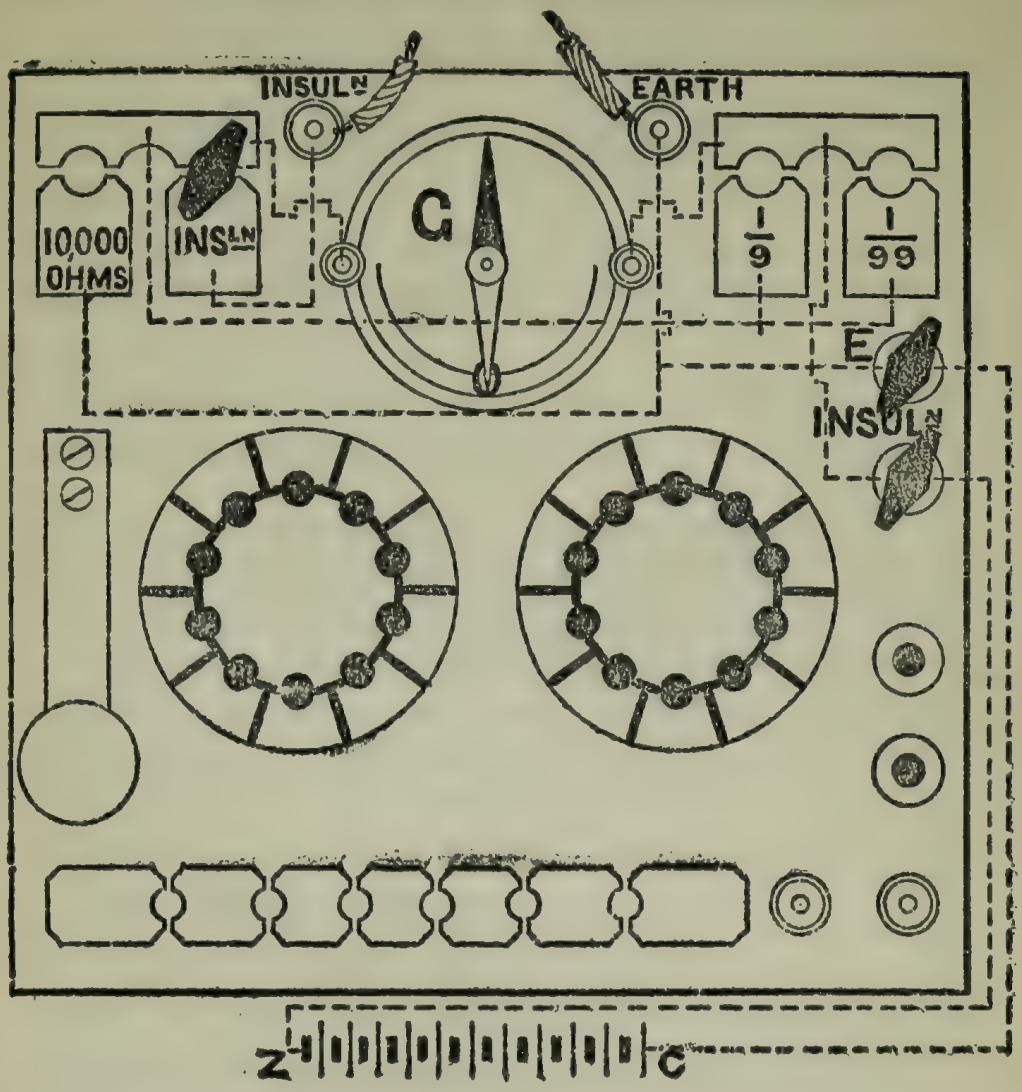
When a balance has been very nearly obtained the key, K, should be repeatedly pressed down, and the glass face of the galvanometer slightly tapped in order to induce the needle to swing or deflect.

Example I.—Let $a = 10$, $b = 10$, and $R = 52$.

Then $a \times x = b \times R$.

$10 \times x = 10 \times 52$.

$x = 52\ \omega$.



PLAN OF APPARATUS FOR INSULATION RESISTANCE.

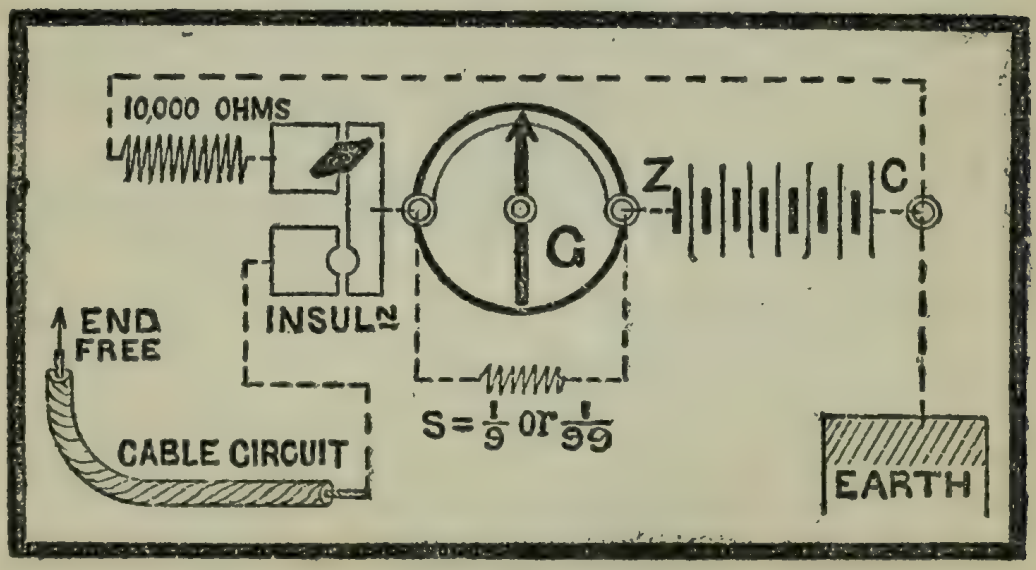


DIAGRAM FOR CONSTANT OF GALVANOMETER AND INSULATION TESTS.

Example II.—Let $a = 10$, $b = 1{,}000$, and $R = 52$.

$$\text{Then} \quad a \times x = b \times R.$$
$$10 \times x = 1{,}000 \times 52.$$
$$x = 100 \times 52 = 5{,}200\ \omega.$$

Example III.—Let $a = 100$, $b = 10$, and $R = 52$.

$$\text{Then} \quad a \times x = b \times R.$$
$$100 \times x = 10 \times 52.$$
$$x = \frac{52}{10} = 5{\cdot}2\ \omega.$$

Example IV.—Let $a = 1{,}000$, $b = 10$, and $R = 2$.

$$\text{Then} \quad a \times x = b \times R.$$
$$1{,}000 \times x = 10 \times 2.$$
$$x = \frac{2}{100} = {\cdot}02\ \omega.$$

Insulation Resistance.—Should the insulation resistance of the dielectric or circuit be less than 9900 ohms, then precisely the same connections and the method just described are all that is required, but if it should exceed this amount, then the following instructions must be carried out:—

To Find Constant for Galvanometer.—1. Place the testing set on a level table or stand as before, so that the galvanometer needle points to zero.

2. Connect up the battery 10 to 20 cells as before, but insert the battery wire terminal plugs into the holes marked INSUL, C and Z.

3. Plug up the 10,000 ohm coil and the shunt, $s_1 = \frac{1}{9}$ or $\frac{1}{99}$ shunt as required in order to obtain a suitable deflection, d_1, of the galvanometer needle (as near 45° as possible).

Then, since the multiplying power of the shunt, s_1, used

$$\text{is for } s\left(\frac{1}{9}\right) = 10, \text{ and for } s\left(\frac{1}{99}\right) = 100,$$

We have

$$\text{Constant} = d_1 \times s_1 \times 10{,}000.$$

To compare the insulation resistance of circuit with the 10,000 ohm coil.

4. Connect the terminal marked "EARTH" to any convenient and near gas or water pipe, and that marked "INSUL" on left hand of galvanometer to the conductor of the cable or circuit whose insulation is required, taking care to "FREE" or insulate the further end.

5. Plug up the hole marked "INSUL" next the terminal "INSUL," by removing the plug from the 10,000 ohm coi and inserting *it* in this hole.

6. Now observe the deflection, d_2, of the galvanomete needle, and by plugging the shunt, s_2, to $\frac{1}{9}$ or $\frac{1}{99}$, or by removing it from either, try to obtain a deflection as near as possible equal to d_1.

Then the INSULATION RESISTANCE

$$R_1 = \frac{\text{Constant}}{d_2 \times s_2} \text{ ohms.}$$

$$= \frac{d_1 \times s_1 \times 10{,}000}{d_2 \times s_2} \text{ ohms.}$$

If no shunt, s_2, has been used, then

$$R_1 = \frac{\text{Constant}}{d_2}.$$

Example I.—Let

$$d_1 = 45°, \text{ and } s_1 = \frac{1}{99},$$

$$\text{and } d_2 = 20°, \text{ and } s_2 = \frac{1}{9}.$$

Then

$$R_1 = \frac{45 \times 100 \times 10{,}000}{20 \times 10} = 225{,}000 \text{ ohms.}$$

Example II.—Let constant be the same as before, but $d_2 = 5°$, and s_2, infinity or no shunt.

Then

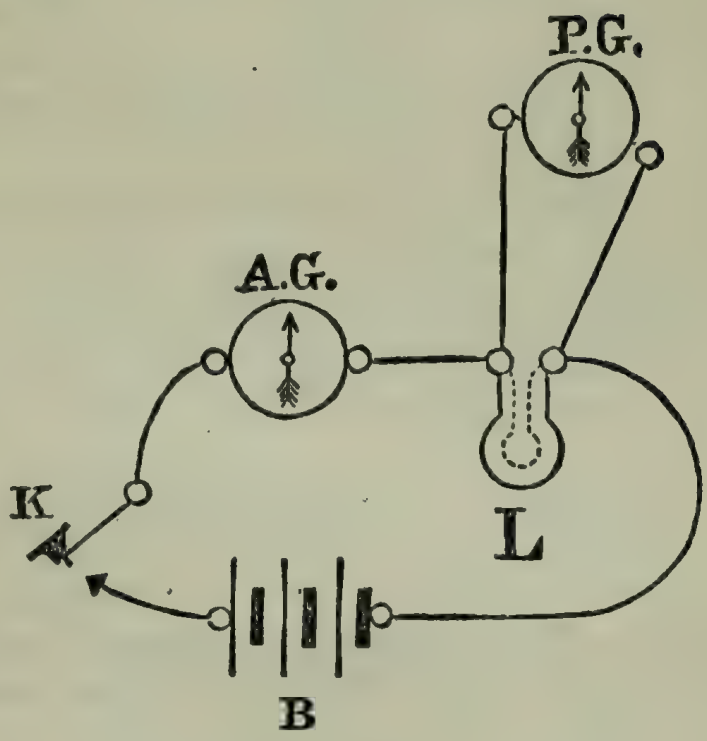
$$R_1 = \frac{45 \times 100 \times 10{,}000}{5} = 9{,}000{,}000 \text{ ohms.}$$

$$= 9\ \Omega \text{ (or megohms).}$$

ELECTRIC-LIGHT TESTS.

By A. Jamieson.

LAMPS.—Connect as in the figure.



L = The electric lamp (arc or incandescent).
B = The generator of electricity (battery or dynamo).
K = Key for completing the circuit.
A G = Ampere galvanometer of very low resistance, for measuring the current strength (C) in amperes.
P G = Potential galvanometer of high resistance, for measuring the difference of potential (E) in volts, between the terminals of the lamp.

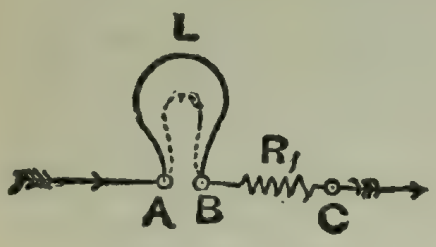
The lamp is placed in a suitable photometer, and simultaneous readings of the candle power, c.p., the current, C, and E.M.F., E., are taken. Then by Ohm's law, $C = \frac{E}{R}$

Resistance hot, R, in Ohms of lamp, . .	$= \frac{E}{C}$
Electrical power in Watts spent on lamp, . .	$= E \times C$
Energy per second in kilogrammetres, . .	$= E \times C \times 0{\cdot}10192$
Power in horse-power spent on lamp, . .	$= \frac{E \times C}{746}$
Number of lamps per horse-power, . . .	$= \frac{746}{E \times C}$
Candles per horse-power,	$= \frac{c.p. \times 746}{E \times C}$
Heat units per second per candle in gramme degrees, ...	$= \frac{E \times C \times 0{\cdot}24}{c.p.}$
Watts per candle, . .	$= \frac{E \times C}{c.p.}$

In the case of incandescent lamps, the *resistance cold*, *r*, of lamp is best found by the Wheatstone bridge, using a very low battery power, say 1 or 2 cells, as the resistance falls quickly if the carbon filament becomes heated. See p. 389.

Testing a Lamp at Work.—Insert a known resistance, R_1, in circuit with the lamp, L, between B and C. Connect an electrometer, or a condenser and galvanometer, or high res. galvanometer, to the terminals of the lamp, A B, and note the deflection, d_1. Then connect the instrument to B and C, and note the deflection, d_2.

The resistance of the lamp, $R = R_1 \frac{d_1}{d_2}$



The electro-motive force on the lamp is found by comparing d_1 with the deflection given by a standard cell on the instrument. Let this be d_3. Then the E.M.F. on the lamp.

$$E_L = E \cdot \frac{d_1}{d_3}$$

Where E is the E.M.F. of the cell. Similarly

$$\textit{The current} \text{ on the lamp} = \frac{E_L}{R} = \frac{E}{R_1} \cdot \frac{d_2}{d_3}$$

LEADS—In selecting *insulated* leading wires for Electric Light or Transmission of Power circuits, careful tests should be made of the different specimens supplied, both for copper resistance or percentage conductivity, and for insulation resistance.

Preliminary Tests.—The *percentage conductivity* of the conductor should never be less than 98 per cent. of that of pure copper, and the test may be made by one or other of the methods given at pp. 94–100, and 190–192.

The *insulation resistance* (of the dielectric) may be found by any of the plans explained at pp. 104, 146, and 151. In using the method at p. 146, which is the one most commonly adopted, the resistance, *br*, is removed, and the galvanometer shunt, *s*, may be dispensed with if the resistance, *r*, is sufficiently great. All the instruments required being a dead beat mirror galvanometer, G, of 1,000 ohms, a high resistance box, *r*, of from 10,000 to 100,000 ohms, a plug or switch commutator, P C, a battery key, K_1, and a battery, B, of as many cells as can be got together, for the greater the E.M.F. applied the more searching the test. In the case of leads likely to be subjected to damp, such as subterranean wires or those fitted on board ship, the test should be as searching as possible, and coils of each size of lead of a known length, say not less than 100 feet (but the greater the length the better), should be immersed in salt, sea, or brine water (the temperature being observed, or the whole brought to 75° Fah.) for 24 hours. One end of the core should be cut down and insulated (see p. 136 at foot), and the other end, after being similarly treated, should be fixed to the plug commutator, P C (see fig., p. 146), a metal earth-plate being inserted into the water-tank and connected to K_1 for an earth or return circuit. As the insulation resistance to be noted is not so high, and the

length not so great as in the case of submarine cables, it will be quite sufficient for all practical purposes to observe first the deflection, d_1, obtained through the high resistance, r, when the *constant* of the galvanometer will be, Rd_1, where $R = B + G + r$, or roughly, $G + r$, if the battery has not much resistance; then obtain deflection, d_2, with the lead in circuit, by applying to it the — pole of the battery, when the absolute resistance will be = the *constant* divided by d_2, which should not be less than 10 megohms for 100 feet of lead in the case of ship-lighting or ordinary land work for damp places.

Example.—Let $r = 100{,}000$ ohms, $G = 1{,}000$ ohms, then $R = G + r = 101{,}000$ ohms; let $d_1 = 500$ divisions, and $d_2 = 5$ divisions, then the absolute resistance of the dielectric of the lead $= 101{,}000 \times 500 \div 5 = 10{,}100{,}000$ ohms $= 10{\cdot}1$ megohms.

Tests during the operation of fitting up or "wiring the leads" should be frequently applied, by placing a sensitive detector galvanometer and a battery of a few cells in direct circuit with the lead, to prove the continuity of the conductor and the joints, as well as to find out that no short circuiting or earthing has taken place at any point. The leading hand on the job should in fact apply this test to each circuit daily, as the work progresses.

Final Tests.—When the whole of the leads have been fitted, a careful test for copper resistance should be taken of each circuit from the main dynamo commutator, *i.e.*, the ends of the furthest branch leads should be clamped or twisted firmly together (or if there be only one, put to earth), and the copper resistance taken by the Wheatstone Bridge method (see p. 96); this resistance should be a minimum, and not exceed the calculated resistance for the sum of the resistances of the several lengths of conductor in circuit. If there should be any doubt about any of the other branch circuit joints, terminals, or connections, similar resistance tests may be taken by joining them *only* in circuit.

A careful insulation resistance test of each circuit, and finally of the whole of the circuits, including all switches and terminals, (but not necessarily the lamps) joined up together should now be taken by the method described above, and not passed, unless the res. is at least equal to ·1 Ω per lamp for every volt employed. The insulation res. of dynamo coils should be equally good. (See p. 180.)

It is only by electricians insisting on such tests being faithfully carried out, and the information they disclose acted upon, that electric light and transmission of power installations will be creditably done.

See Index for size of leading wires for ships, &c.

EFFICIENCY.—In testing the efficiency of a dynamo, the lamp, L (fig. p. 176), is replaced by resistance coils of German silver, iron, or aluminium bronze wire, or, better, by thin ribands of these metals, and the battery, B, by the dynamo. With different resistances in circuit, readings are taken on the galvanometers. At the same time, the mechanical H.P. applied to the dynamo, by belt or otherwise, is measured by a suitable dynamometer (p. 409).

If H.P. = the horse-power transmitted to the dynamo, and $\left(\frac{E \times C}{746}\right)$ = the electrical, H.P., converted into heat in the resistance coils or external circuit—*i.e.*, the useful electrical horse-power given out by dynamo,

Then the efficiency $= E \times C \div 746 \times$ H.P.

For example, take the trial of a Crompton-Bürgen Dynamo.

Where C = current through A.G. = 30·7 amperes, E = C × R = 30·7 × 3·31 = 101·6 volts, and H.P. = 6·4, the power measured on brake.

∴ Percentage efficiency $= 100 \times E \times C \div 746 \times$ H.P. $= 65{\cdot}3\,\%$.

INSULATION.—New dynamos to give, after 1 hour's run at full power, not less than at the rate of 1 Ω per lamp for every volt generated, between frame and armature with F.M. coils in circuit; and the same between series and shunt F.M. coils. *Ex.*—A 100 incandescent light dynamo of 100, V, E.M.F. to give 1 Ω; a 200 one of 50, V, to give ·25 Ω. and so on for other sizes. See *Proc. Inst. C.E.*, vol. lxxix. p. 91.

See pp. 369 to 381 for further information on dynamos.

SECONDARY BATTERIES OR ACCUMULATORS.—In charging secondary batteries, the battery to be charged replaces L (see fig., p. 176), and a dynamo, if used, takes the place of B. Readings are taken for C and E at frequent intervals. From these the power of charging current is found in Watts. In estimating the total work done in charging, time must be taken into account.

In testing the discharge, the battery takes the place of B, and resistance coils or lamps that of L in fig., p. 176. C and E are noted, and the energy, as well as total work done in Watts, obtained as before.

∴ The efficiency of the secondary battery

$$= \frac{\text{the total work given out}}{\text{the total work put in}}.$$

If E_1 = E.M.F. of accumulator disconnected in volts.
E_2 = difference of potential at accumulator terminals while charging in volts.
C_1 = charging current in amperes.
T_1 = time of charging in seconds.

Then, $C_1 E_2 T_1$ = work wasted in Joules, by heating the accumulator while charging.

Or, $C_1 E_2 T_1 \times \cdot 7373 =$ foot-pounds wasted in heat during charge.

Again,

If $E_3 =$ difference of potential at accumulator terminals during discharge.

$C_2 =$ average current of discharge.

$T_2 =$ time of discharge in seconds.

Then, $C_2 (E_1 - E_3) T_2 =$ work wasted in Joules, in heating accumulator during discharge.

Or, $C_2 (E_1 - E_3) T_2 \times \cdot 7373 =$ foot-pounds wasted in heat during discharge.

And $\frac{E_2}{C_1} = \frac{E_1 - E_3}{C_2} =$ res. of accumulator in ohms.

Transmission of Power.—The efficiency of the transmission of power by electricity may be tested without the aid of electrical apparatus by simply attaching suitable dynamometers to the generator and motor, and taking simultaneous readings. (See index for dynamometer tests.)

Let $P_1 =$ the power applied to generator, and $P_2 =$ the power given out by motor. Then the percentage efficiency $= 100 \frac{P_2}{P_1}$. If, however, we wish to test the system electrically, let the generator replace B, and the motor, L, in fig., p. 176. Attach a potential galvanometer to the terminals of the generator, and place one current galvanometer at each end close to generator and motor. Take simultaneous readings on all four galvanometers. We have, whatever the length and insulation of line wire may be, E_1 and $E_2 =$ E.M.F. in volts; C_1 and $C_2 =$ current in amperes at generator and motor respectively.

Then

$E_1 C_1 =$ power given out by generator in Watts.

$E_2 C_2 =$,, received by motor ,,

The electrical efficiency of the system $= \frac{E_2 C_2}{E_1 C_1}$.

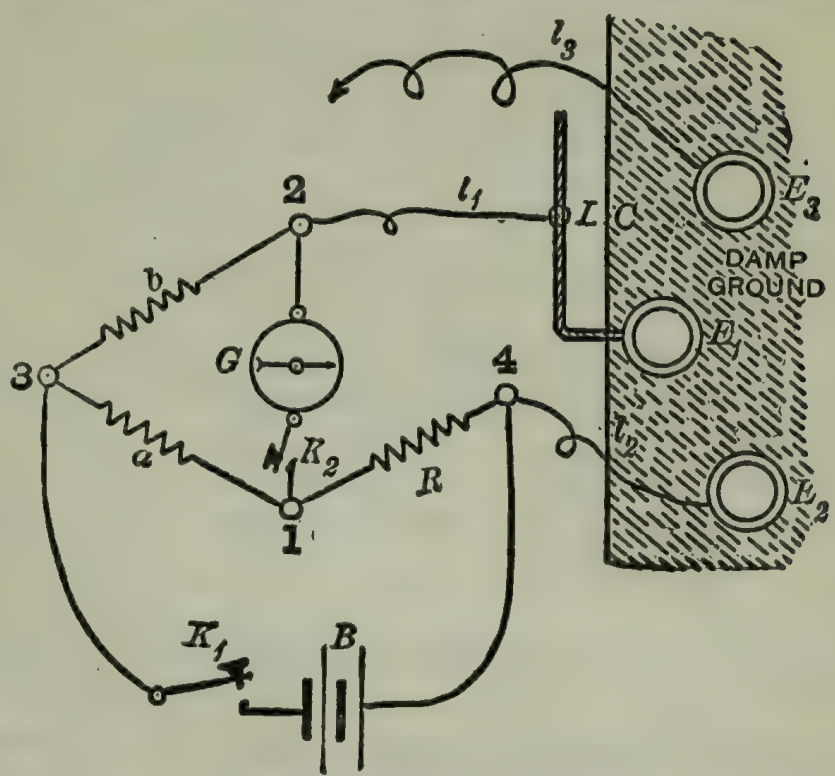
If we wish the motor to give out power most rapidly, the above efficiency will be equal to *one-half;* but if we wish it to do work most economically, then $\frac{E_2 C_2}{E_1 C_1}$ must be a maximum ($= \frac{E_2}{E_1}$ if the insulation of the line wire be perfect and $C_1 = C_2$, when only one current galvanometer is required in circuit).

The ratio of the speeds of motor and generator should not be depended upon as a test of their efficiency. See pp. 375, 376.

TESTING—LIGHTNING CONDUCTORS.

By A. Jamieson.

See Index for Erection of Lightning Conductors.



Join up as in diagram for Wheatstone bridge test (*see Index*).

L C = lightning conductor whose "absolute" resistance to earth at E_1 is required.

E_2 and E_3 = two other separate and independent earths, such as sunk copper plate and suction pipe of a water-pump, at least 10 feet from E_1.

l_1, l_2, l_3, = the leading wires soldered to earths, E_1, E_2, E_3.

G = a dead beat sensitive Thomson's reflecting galvanometer.

B = a constant Daniell's battery, 2 or 3 cells.

*Method of Taking Tests.**

Let l_1 = resistance of the leading wire to earth, E_1.

Let E_1 = resistance of the earth to be determined.

Let E_2 and E_3 = the resistances of the two other earths *including* their leading wires, l_2 and l_3 (their individual values not being required).

Let R_1, R_2, R_3 = the respective resistances unplugged in the third or adjustable arm of the Wheatstone bridge *multiplied by* the ratio $\frac{a}{b}$ of the bridge arms used *in each case* (when measuring the resistances between earths, E_1 and E_2, E_1 and E_3, E_2 and E_3).

From these the following equations are found:

(1) $R_1 = l_1 + E_1 + E_2$ hence (4) $E_2 = R_1 - l_1 - E_1$
(2) $R_2 = l_1 + E_1 + E_3$ hence (5) $E_3 = R_2 - l_1 - E_1$
(3) $R_3 = E_2 + E_3$.

Substituting the values for E_2 and E_3 from equations (4) and (5) in equation (3),

$$R_3 = E_2 + E_3$$

we have $$R_3 = R_1 - l_1 - E_1 + R_2 - l_1 - E_1$$

$$\therefore R_3 = R_1 + R_2 - 2E_1 - 2l_1$$

Hence $$E_1 = \frac{R_1 + R_2 - R_3 - 2l_1}{2}$$

or $$E_1 = \frac{R_1 + R_2 - R_3}{2} - l_1.$$

* See letter by Geo. Edwin Fletcher, *Electrical Review*, April 27, 1888, p. 464.

Example.—

If $R_1 = 2\omega$; $R_2 = 1{\cdot}5\omega$; $R_3 = 1{\cdot}6\omega$, and $l_1 = {\cdot}2\omega$,

Then, $$E_2 = \frac{2 + 1{\cdot}5 - 1{\cdot}6}{2} - {\cdot}2 = {\cdot}75.$$

F. H. POMEROY'S METHOD.

Test 1.—Connect up precisely as in the last figure. (When the earths are at telegraph stations let, E_2, be the home station earth, l_1, stand for the telegraph line and, E_1, for the earth at distant station).

Then if, a, and, b, are equal, and a balance has been obtained when, $R_1\omega$, are in the arm, R, shown in figure

$$R_1 = l_1 + E_1 + l_2 + E_2.$$

Test 2.—Disconnect the copper pole of the battery from the earth, E_2, or point 4, and join it on to another line, l_3 and earth E_3 as far as possible in a different direction from E_1 and E_2. Now increase the E.M.F. of the battery so as to preserve approximately the same difference of potential at the bridge as in test 1.

This test will give the difference of resistance between $(l_1 + E_1)$ and $(l_2 + E_2)$.

Then if, a, and, b, are equal, and a balance has been obtained when, $R_2\omega$, are in the arm, R, shown in the figure

$$R_2 = l_1 + E_1 - l_2 = E_2$$

but $$R_1 = l_1 + E_1 + l_2 + E_2$$

$$\therefore R_1 - R_2 = 2(l_2 + E_2)$$

or $$\frac{R_1 - R_2}{2} = E_2 \text{ (neglecting lead } l_2)$$

E_2 is the resistance of the earth required.

It follows that when the earth is perfect, $R_2 = R_1$, and no calculation is required.

If the arms, a, and, b, are unequal, we get from test 2 (neglecting or subtracting resistance of lead, l_2),

$$\frac{a}{b}(R_2 + E_2) = l_1 + E_1.$$

Then the resistance of earth, $E_2 = \dfrac{a(R_1 - R_2)}{a + b}$.

All lightning conductors should be tested once a year in the dry season, and not be considered satisfactory unless they give less than 1 ohm, including the whole conductor and the earth resistance.

Logarithms of Multiplying Powers of Shunts for Galvanometers of 7000 Ohms Resistance.

The resistances of marine, astatic, and dead-beat galvanometers for testing are often made about 6,000 ohms at 60° Fah. Before taking a test, introduce a resistance in direct circuit with the galvanometer, in order to make the total resistance equal to 7,000 ohms; the following tables by Clark, Forde, & Co., give the logs of the multiplying powers of the shunts employed.

Res. of Shunt.	Log. $\frac{G+S}{S}$	Res. of Shunt.	Log. $\frac{G+S}{S}$	Res. of Shunt.	Log. $\frac{G+S}{S}$
1	3·84516	31	2·35565	61	2·06354
2	3·54419	32	2·34193	62	2·05653
3	3·36816	33	2·32863	63	2·04965
4	3·24329	34	2·31572	64	2·04287
5	3·14644	35	2·30320	65	2·03620
6	3·06732	36	2·29102	66	2·02963
7	3·00043	37	2·27919	67	2·02316
8	2·94250	38	2·26767	68	2·01679
9	2·89141	39	2·25645	69	2·01051
10	2·84572	40	2·24551	70	2·00432
11	2·80439	41	2·23485	71	1·99822
12	2·76666	42	2·22445	72	1·99221
13	2·73196	43	2·21429	73	1·98628
14	2·69984	44	2·20437	74	1·98043
15	2·66994	45	2·19467	75	1·97466
16	2·64197	46	2·18518	76	1·96897
17	2·61570	47	2·17591	67	1·96336
18	2·59094	48	2·16682	78	1·95782
19	2·56752	49	2·15793	79	1·95234
20	2·54531	50	2·14922	80	1·94694
21	2·52418	51	2·14068	81	1·94161
22	2·50404	52	2·13231	82	1·93634
23	2·48479	53	2·12410	83	1·93114
24	2·46637	54	2·11604	84	1·92600
25	2·44871	55	2·10813	85	1·92092
26	2·43173	56	2·10037	86	1·91590
27	2·41541	57	2·09274	87	1·91094
28	2·39967	58	2·08525	88	1·90604
29	2·38449	59	2·07789	89	1·90119
30	2·36983	60	2·07065	90	1·89640

MULTIPLYING POWERS OF SHUNTS FOR GALVANOMETERS OF 7000 OHMS.

Res. of Shunt.	Log. $\frac{G+S}{S}$	Res. of Shunt.	Log. $\frac{G+S}{S}$	Res. of Shunt.	Log. $\frac{G+S}{S}$
91	1·89167	205	1·54588	355	1·31635
92	1·88698	210	1·53572	360	1·31058
93	1·88235	215	1·52580	365	1·30488
94	1·87776	220	1·51611	370	1·29927
95	1·87323	225	1·50666	375	1·29373
96	1·86874	230	1·49741	380	1·28827
97	1·86430	235	1·48837	385	1·28289
98	1·85991	240	1·47953	390	1·27758
99	1·85556	245	1·47087	395	1·27234
100	1·85126	250	1·46240	400	1·26717
105	1·83037	255	1·45410	405	1·26207
110	1·81048	260	1·44596	410	1·25703
115	1·79148	265	1·43799	415	1·25206
120	1·77330	270	1·43017	420	1·24715
125	1·75587	275	1·42250	425	1·24231
130	1·73915	280	1·41497	430	1·23752
135	1·72306	285	1·40759	435	1·23279
140	1·70757	290	1·40033	440	1·22812
145	1·69263	295	1·39320	445	1·22350
150	1·67821	300	1·38620	450	1·21894
155	1·66428	305	1·37932	455	1·21444
160	1·65079	310	1·37256	460	1·20998
165	1·63773	315	1·36590	465	1·20558
170	1·62507	320	1·35936	470	1·20122
175	1·61278	325	1·35293	475	1·19692
180	1·60085	330	1·34659	480	1·19266
185	1·58925	335	1·34036	485	1·18845
190	1·57797	340	1·33422	490	1·18429
195	1·56700	345	1·32817	495	1·18017
200	1·55630	350	1·32222	500	1·17609

MULTIPLYING POWERS OF SHUNTS FOR GALVANOMETERS OF 7000 OHMS.

Res. of Shunt.	Log. $\frac{G+S}{S}$	Res. of Shunt.	Log. $\frac{G+S}{S}$	Res. of Shunt.	Log. $\frac{G+S}{S}$
510	1·16807	810	0·98417	1550	0·74163
520	1·16022	820	0·97939	1600	0·73038
530	1·15252	830	0·97468	1650	0·71953
540	1·14498	840	0·97004	1700	0·70907
550	1·13758	850	0·96545	1750	0·69897
560	1·13033	860	0·96092	1800	0·68921
570	1·12322	870	0·95645	1850	0·67977
580	1·11624	880	0·95204	1900	0·67064
590	1·10939	890	0·94769	1950	0·66179
600	1·10266	900	0·94338	2000	0·65321
610	1·09605	910	0·93914	2050	0·64480
620	1·08956	920	0·93494	2100	0·63682
630	1·08318	930	0·93079	2150	0·62898
640	1·07691	940	0·92669	2200	0·62136
650	1·07075	950	0·92264	2250	0·61396
660	1·06468	960	0·91864	2300	0·60676
670	1·05872	970	0·91469	2350	0·59974
680	1·05285	980	0·91078	2400	0·59292
690	1·04708	990	0·90691	2450	0·58627
700	1·04139	1000	0·90309	2500	0·57978
710	1·03580	1050	0·88461	2550	0·57346
720	1·03028	1100	0·86709	2600	0·56730
730	1·02486	1150	0·85046	2650	0·56128
740	1·01951	1200	0·83463	2700	0·55541
750	1·01424	1250	0·81954	2750	0·54967
760	1·00905	1300	0·80513	2800	0·54407
770	1·00393	1350	0·79135	2850	0·53859
780	0·99888	1400	0·77815	2900	0·53324
790	0·99391	1450	0·76549	2950	0·52800
800	0·98900	1500	0·75333	3000	0·52288

MULTIPLYING POWERS OF SHUNTS FOR GALVANOMETERS OF 7000 OHMS.

Res. of Shunt.	Log. $\frac{G+S}{S}$	Res. of Shunt.	Log. $\frac{G+S}{S}$	Res. of Shunt.	Log. $\frac{G+S}{S}$
3050	0·51787	4550	0·40457	7100	0·29796
3100	0·51296	4600	0·40170	7200	0·29496
3150	0·50816	4650	0·39887	7300	0·29201
3200	0·50345	4700	0·39609	7400	0·28913
3250	0·49884	4750	0·39334	7500	0 28631
3300	0·49432	4800	0·39064	7600	0·28354
3350	0·48990	4850	0·38798	7700	0·28083
3400	0·48553	4900	0·38535	7800	0·27817
3450	0·48130	4950	0·38276	7900	0·27559
3500	0·47712	5000	0·38021	8000	0·27300
3550	0·47302	5100	0·37522	8100	0·27049
3600	0·46900	5200	0·37036	8200	0·26803
3650	0 46506	5300	0·36563	8300	0·26561
3700	0·46118	5400	0·36103	8400	0·26324
3750	0·45738	5500	0·35655	8500	0·26091
3800	0·45364	5600	0·35218	8600	0·25863
3850	0·44997	5700	0·34793	8700	0·25638
3900	0·44636	5800	0·34378	8800	0·25417
3950	0·44282	5900	0·33974	8900	0·25201
4000	0·43933	6000	0·33579	9000	0·24988
4050	0·43591	6100	0·33194	9100	0·24778
4100	0·43254	6200	0·32818	9200	0·24573
4150	0·42923	6300	0·32451	9300	0·24370
4200	0·42597	6400	0·32092	9400	0·24172
4250	0·42276	6500	0·31742	9500	0·23976
4300	0·41961	6600	0·31399	9600	0·23784
4350	0·41651	6700	0·31065	9700	0·23594
4400	0·41345	6800	0·30737	9800	0·23408
4450	0·41045	6900	0·30417	9900	0·23225
4500	0·40749	7000	0·30103	10000	0·23045

CONDUCTORS.

Copper.

The **specific gravity** of pure annealed copper wire is about = 8·9 at 60° Fah.

One cubic foot weighs about 555 lbs.

One cubic inch weighs 0·32 lbs.

The **melting point** of copper is about 2000°F.

The **strength** of a wire or strand is $1\frac{1}{2}$ lb. per pound weight per knot—*i.e.*, a strand weighing 200 lbs. per knot would bear 300 lbs., and stretch from 10 to 15 per cent. before breaking.

The **weight per knot** of a round copper wire is about $\frac{d^2}{55}$ lbs.; and for a strand $\frac{d^2}{70 \cdot 4}$ lbs.

The **weight per mile** of a round copper wire is about $\frac{d^2}{62 \cdot 5}$, where, d, is the diameter in mils. or ·001 inch.

The **diameter** of a copper wire weighing w lbs. per knot, is about $7 \cdot 4 \sqrt{w}$ mils., and for a strand about $8 \cdot 4 \sqrt{w}$ mils.

The weight and resistance of a copper strand cannot be found exactly by multiplying the above results for one wire, by the number of wires composing the strand, and no fixed constant can be given, as the lay of the strand and the diameters of wires vary.

The **specific resistance** of pure copper, or the resistance of a cubic centimetre at 0° Cent. = ·000,001,642 ohm, and of a cubic inch at 0° Cent. = ·000,000,64 ohm. See pp. 194*a* and 194*b*.

The **resistance** of a knot of pure copper wire weighing 1 lb. is 1196·75 ohms at 75° Fah.

The resistance per knot of any pure copper wire, d mils. in diameter, is $\frac{65306}{d^2}$ ohms at 75° Fah.

The resistance per statute mile (1760 yards) of any pure copper wire, d mils. in diameter, is $\frac{54892}{d^2}$ ohms at 60° Fah.

From which we get the *resistances of copper wire per* 100 yards at 60° Fah.

The **specific conductivity** of pure copper is taken as 100. The copper used for telegraphic and electric lighting conductors is of lower conductivity, or, in other words, of higher resistance, but ought never to be under 98 per cent. of that of pure copper.

The **percentage conductivity** of any wire is found by multiplying the resistance of a pure wire of the same length and weight at the same temperature by 100, and dividing the product by the resistance of the wire as measured.

Matthiessen standard = 0·1516 ohms at 60° Fah., which is the resistance of 100 inches of pure annealed copper wire weighing 100 grains. Wire is now made of higher conductivity than Matthiessen's standard. Taking the latter at 100, Elmore's electro-deposited wire is 102·38. Samples of pure copper wire of different gauges are obtainable for measuring the specific conductivity of conducting wires. All copper wire intended for telegraphic or electric lighting or telephonic purposes, should be carefully tested before being accepted. See index for methods employed.

The test for percentage conductivity is most accurately and easily made by the "difference of potential" method, p. 94, or by Thomson's mhometer.

At pp. 195 to 200 will be found tables of resistances of copper wires at various temperatures for

different units of length - weight, such as foot-grain, metre-gramme, and of a knot-pound.

Let R_t = the resistance of unit length-weight at temp. t, from tables.
l = the length of the wire under test.
w = the weight ,, ,, ,,
r_1 = the calculated resistance in ohms at temp. t, for *pure wire.*
r_2 = the observed resistance in ohms at temp. t of the wire under test.

Then, since the resistance of a wire is directly as its length and inversely as its weight per unit length.

By compound proportion

$$1 : l : R_t : r_1$$
$$\frac{w}{l} : 1$$

$$\therefore r_1 = \frac{R_t\, l^2}{w} \text{ ohms.}$$

But by actual measurement we find the resistance of the wire at temp. t to be r_2 ohms.

$$\therefore r_2 : r_1 :: 100 : x$$

or the percentage conductivity of the wire

$$x = 100 \frac{r_1}{r_2}$$

Example I.—Two knots, l, of copper strand weighing 214 lbs., w, have a resistance of 23 ohms, r_2, at temp. 75° Fah., t, what is the percentage conductivity? From the knot-pound tables, p. 199, R_t = 1196·7 ohms at 75° Fah.

$$\therefore r_1 = \frac{1196 \cdot 7 \times 4}{214} = 22 \cdot 368 \text{ ohms,}$$

and

$$x = 100 \frac{r_1}{r_2} = \frac{100 \times 22 \cdot 368}{23} = 97 \cdot 2 \text{ per cent.}$$

Example II.—50 feet, l, of No. 16, Board of Trade new standard gauge, S. W. G., copper wire; 4,200 grains, w, have a resistance of ·135 ohms, r_2, at 59° Fah. From the foot-grain table p. 197, R_t = ·2186 ohms at 59° Fah.

$$\therefore r_1 = \frac{\cdot 2186 \times 50^2}{4200} = \cdot 130 \text{ ohms,}$$

and

$$x = 100 \frac{r_1}{r_2} = \frac{100 \times \cdot 130}{\cdot 135} = 96 \cdot 3 \text{ per cent.}$$

The **resistance per knot** of a cable conductor at 75° Fah., is roughly = 120,000 divided by the product of the percentage conductivity of the copper and its weight per knot in lbs.; or the resistance of a knot-pound corresponding to the percentage conductivity as given in table, pp. 199, 200, and divided by the weight in lbs. per knot.

The **resistance of copper** increases as the temperature rises, about 0·21 per cent. for each degree Fah., or about 0·38 per cent. for each degree Cent.

The **standard temperature** for copper resistance of Submarine Cable Conductors is 75° Fah. To calculate what will be the resistance at 75°, multiply the observed resistance by the coefficient in tables, pp. 201, 202, opposite the temp., or by pp. 203, 204 *add* to the log. of the actual resistance the log. opposite the temperature in the table, and their sum = the log. of the res. at 75°. To use this table for temperatures above 75°, take the same number of degrees below 75, and *subtract* the log. opposite from the log. of the actual res.

Ex.—Let the temperature = 82°, then 82 − 75 = 7, ∴ 75 − 7 = 68. Referring to table, the log. opposite 68 = ·00638, which subtracted from the log. of observed res. gives the log. of res. at 75° Fah.

Kempe's tables, pp. 201, 202, may be used without logs.

Temperature and resistance (Matthiessen). — The resistance of metals increases with temperature after the following empirical formula :—

$$R = r(1 + a\,t \pm b\,t^2)$$

Where R = resistance at the temperature t.
r = ,, at 0°C.
t = temperature in degrees C.

a and b are numerical constants with values as below.

	a	*b*
Metals (very pure),	0·003824	+0·00000126
Mercury, . .	0·0007485	−0·000000398
German silver, .	0·0004433	+0·000000152
Alloy of silver and platinum, . .	0·00031	,,
Alloy of silver and gold, . . .	0·0006999	−0·000000062

Correction for Impure Metals.

Let R = resistance at temp. t,
R_1 = ,, ,, t_1,
$\varkappa$ = temperature coefficient for pure metal
$\varkappa_1$ = ,, ,, impure ,,
C_1 = specific conductivity ,, ,,
100 = ,, ,, pure ,,

$$\text{Then } R_1 = R\,\varkappa_1$$

$$\text{Where } \varkappa_1 = 1 + \frac{C_1}{100}(\varkappa - 1)$$

Example.—In table, p. 202, the correction coefficient for $t = 45°$ F., and $t_1 = 75°$ F., is 1·0657 for *pure* copper.

Then for 96 per cent. spec. conductivity,

$$\kappa_1 = 1 + \frac{96}{100}(1{\cdot}0657 - 1) = 1{\cdot}06307.$$

Comparative Resistance of Woods (Addenbrooke).—The measurements were made along the grain by inserting terminals 2 inches apart in sound, dry, well-seasoned pieces of the woods, each piece being $3'' \times \frac{7}{8}'' \times \frac{5}{8}''$. Other tests across the grain gave results from 50 to 100 per cent. higher.

Wood.	Megohms.	Wood.	Megohms.
Mahogany, . .	48	Lignum Vitæ, .	397
Pine, ...	214	Walnut, . . .	478
Rosewood, . .	291	Teak, . . .	734

Specific Resistance of Copper Wire.—Resistance of annealed (soft) copper at 0° C. = ·02057 B.A. ohms for wire 1 metre long, and 1 millimetre diameter (*vide* B.A. Reports on Electrical Standards, pp. 227, 228).

∴ resistance of cubic centimetre at 0° C.

$$= \cdot 02057 \times \cdot 7854 \times \cdot 0001 = \cdot 0000016156.$$

To reduce this result to true ohms (106·3 centimetres of mercury of 1 sq. m.m. section), we must multiply it by ·98613; or the resistance in true ohms of a cubic centimetre at 0° C.

$$= \cdot 0000016156 \times \cdot 98613 = \cdot 0000015932$$
$$= 1593 \cdot 2 \text{ C.G.S. units.}$$

One foot-grain of soft copper

has a resistance of ·2186 B.A. units at 15° C.

and ,, ·2194 ,, ,, 16° C.

∴ its resistance at 15·5° C. or 60° F.

$$= \frac{\cdot 2186 + \cdot 2194}{2} = \cdot 2190;$$

and its resistance at 0° C. = ·2064.

∴ The resistance of a cubic centimetre at 60° F.

$$= \cdot 0000016156 \times \frac{\cdot 2190}{\cdot 2064} = \cdot 0000017142 \text{ B.A. units,}$$

or $\cdot 0000017142 \times \cdot 98613 = \cdot 0000016904$ true ohms.

$$= 1690 \cdot 4 \text{ C.G.S. units} = 1642 \text{ at } 0° \text{ C.}$$

To find the resistance of a wire in legal ohms, the specific resistance in C.G.S. units being given.

Let ρ = specific resistance in C.G.S. units.
l = length in c.m.
d = diameter in c.m.

Let L = length in inches.
D = diameter in inches.
R = resistance in legal ohms.

$$\text{Then } R = \frac{4l\rho}{\pi d^2} \text{ C.G.S. units.}$$

Now $l = L \times 30{\cdot}48$ 1 ft. = 30·48 c.m.
$d = D \times 2{\cdot}54$ $2{\cdot}54^2 = 6{\cdot}4516$.

In the case of a wire when L and D are given,

$$R\omega = \frac{4 \times L \times 30{\cdot}48 \times \rho}{\pi D^2 \times 6{\cdot}4516 \times 10^9}$$

$$= \frac{4 \times 30{\cdot}48}{3{\cdot}1416 \times 6{\cdot}4516 \times 10^9} \times \frac{L \times \rho}{D^2}$$

$$= \frac{6{\cdot}0153}{10^9} \times \frac{L \times \rho}{D^2}.$$

Example.—What is the resistance of 100 ft. of No 18 S.W.G. copper wire at 60° F.

$$R\omega = \frac{6{\cdot}0153 \times 100 \times 1690{\cdot}4}{{\cdot}048^2 \times 10^9} = {\cdot}4413\ \omega.$$

SPECIFIC RESISTANCE IN C.G.S. (ELECTROMAGNETIC), UNITS at 0° C. (see p. 205).

Silver annealed, .	1521	Iron annealed, .	9827
,, hard-drawn,	1652	Nickel, . . .	12600
Copper annealed,	1615	Tin, ...	13360
,, hard-drawn,	1642	Lead, . . .	19847
Gold hard-drawn,	2154	Mercury, . .	96146
Zinc, ...	5690	Alloys, . . .	
Platinum annealed,	9158	German Silver,	21170
		Platinoid, . .	34000

SPECIFIC RESISTANCE IN B. A.* UNITS OF METALS AND ALLOYS AT 0° CENTIGRADE FROM DR. MATTHIESSEN'S EXPERIMENTS.—See *Report on Electrical Standards*, by F. Jenkin, p. 227.

Name of Metals.	Resistance of a wire 1 foot long, weighing 1 grain.	Resistance of a wire 1 metre long, weighing 1 gramme.	Resistance of a wire 1 foot long, $\frac{1}{1000}$ inch in diameter.	Res. of a wire 1 metre long, 1 mm. in diam ter.	Approximate Comparative Resistance.	Approximate percentage of variation in resistance per degree of temperature at 20°
Silver, annealed.. . . .	0·2214	0·1544	9·151	0·01937	1	0·377
„ hard-drawn, . . .	0·2415	0·1680	9·936	0 02103	1·09	...
Copper, annealed, see p. 189, .	0·2064	0·1440	9·718	0·02057	1·06	0·388
„ hard-drawn, . . .	0·2106	0·1469	9·940	0·02104	1·09	...
Gold, annealed, ...	0·5849	0·4080	12·52	0·02650	1·38	0·365
„ hard-drawn, . . .	0·5950	0·4150	12·74	0 02697	1·39	...
Aluminium, annealed, . .	0·1085	0·0757	17·72	0·03751	1·94	...
Zinc, pressed, ...	0 5831	0·4067	34·22	0·07244	3·75	0·365
Platinum, annealed, . . .	2·810	1·96	55·09	0·1166	6·08	...

To convert resistance of wire 1 foot long, weighing 1 grain into resistance per knot, multiply by 5293·1, and divide by weight of copper per knot in lbs.

* One B.A. unit equals 0·9889 legal ohm. See p. 14. The above numbers multiplied by 0·9889 give legal ohms; or deduct 1·12 per cent.

SPECIFIC RESISTANCE IN B. A. UNITS OF METALS AND ALLOYS AT 0° CENTIGRADE, FROM DR. MATTHIESSEN'S EXPERIMENTS.

Name of Metals.	Resistance of a wire 1 foot long, weighing 1 grain.	Resistance of a wire 1 metre long, weighing 1 gramme.	Resistance of a wire 1 foot long, $\frac{1}{100}$ inch in diameter.	Res. of a wire 1 metre long, 1 mm. in diameter.	Approximate Comparative Resistance.	Approximate percentage of variation in resistance per degree of temperature at 20°
Iron, annealed, ...	1·097	0·7654	59·10	0·1251	6·80	...
Nickel, annealed, . . .	1·535	1·071	75·78	0·1604	8·30	...
Tin, pressed, ...	1·396	0·9738	80·36	0·1701	8·80	0·365
Lead, pressed, ...	3·236	2·257	119·39	0·2526	13·60	0·387
Antimony, pressed, . . .	3·456	2·411	216·0	0·4571	23·65	0·389
Bismuth, pressed, . . .	18·64	13·03	798·0	1·689	87·20	0·354
Mercury, liquid, ...	18·72	13·06	578·6	1·2247	62·50	0·072
*Platinum-silver alloy, hard or annealed, ...	4·243	2·959	148·35	0·3140	16·10	0·031
†German silver, hard or annealed,	2·652	1·850	127·32	0·2695	14·87	0·044
Gold-silver alloy, hard or annealed, ...	2·391	1·668	66·10	0·1399	7·22	0·065

* The alloy used for B. A. resistance units, 2 parts platinum, 1 part silver, by weight.
† The alloy commonly used for resistance-coils.

RESISTANCE IN B. A.* UNITS OF WIRE 1 FOOT LONG, WEIGHING 1 GRAIN.

Temperature.		Soft Copper.	Hard Copper.	German Silver.†	Platinum Silver.‡
Cent.	Fah.				
0	32	0·2064	0·2106	2·652	4·24
5	41	0·2102	0·2147	2·657	4·25
10	50	0·2144	0·2188	2·661	4·25
11	51·8	0·2153	0·2197	...	...
12	53·6	0·2161	0·2205	...	...
13	55·4	0·2170	0·2214	...	...
14	57·2	0·2178	0·2222	...	...
15	59	0·2186	0·2231	2·666	4·26
16	60·8	0·2194	0·2239	...	...
17	62·6	0·2203	0·2248	...	...
18	64·4	0·2211	0·2256	...	...
19	66·2	0·2220	0·2265	...	...
20	68	0·2228	0·2272	2·67	4·27
21	69·8	0·2237	0·2283	...	...
22	71·6	0·2242	0·2288	...	...
23	73·4	0·2253	0·2299	...	...

* One B. A. unit equals 0·9889 legal ohm. See p. 14. The above numbers multiplied by 0·9889 give legal ohms; or deduct 1·12 per cent.

† Calculated from specific gravity 8·47.

‡ Calculated from specific gravity 12·0. (Approximate values only.)

RESISTANCE IN B. A.* UNITS OF WIRE 1 FOOT LONG, WEIGHING 1 GRAIN—*Continued.*

Temperature.		Soft Copper.	Hard Copper.	German Silver.†	Platinum Silver.‡
Cent.	Fah.				
24	75·2	0·2262	0·2308	...	...
25	77	0·2271	0·2317	2·675	4·27
26	78·8	0·2279	0·2325	...	...
27	80·6	0·2287	0·2334	...	...
28	82·4	0·2296	0·2343	...	...
29	84·2	0·2305	0·2352	...	...
30	86	0·2313	0·2360	2·68	4·28
31	87·8	0·2322	0·2369	...	...
32	89·6	0·2328	0·2375	...	...
33	91·4	0·2340	0·2388	...	...
34	93·2	0·2348	0·2396	...	...
35	95	0·2357	0·2405	2·684	4·28
36	96·8	0·2365	0·2413	...	...
37	98·6	0·2376	0·2424	...	...
38	100·4	0·2383	0·2432	...	...
39	102·2	0·2391	0·2440	...	...
40	104	0·2400	0·2449	2·689	4·29

* One B. A. unit equals 0·9889 legal ohm. See p. 14. The above numbers multiplied by 0·9889 give legal ohms; or deduct 1·12 per cent.

† Calculated from specific gravity 8·47.

‡ Calculated from specific gravity 12·0. (Approximate values only.)

RESISTANCE IN B.A. OHMS OF A KNOT-POUND OF COPPER WIRE OF VARIOUS CONDUCTIVITIES, AT 75° FAH.

Percentage of Conductivity.	Resistance.	Percentage of Conductivity.	Resistance.	Percentage of Conductivity.	Resistance.	Percentage of Conductivity.	Resistance.
100·0	1196·7	98·7	1212·5	97·4	1228·6	96·1	1245·3
99·9	1197·9	98·6	1213·7	97·3	1229·9	96·0	1246·6
99·8	1199·1	98·5	1214·9	97·2	1231·2	95·9	1247·9
99·7	1200·3	98·4	1216·2	97·1	1232·5	95·8	1249·2
99·6	1201·5	98·3	1217·3	97·0	1233·7	95·7	1250·5
99·5	1202·7	98·2	1218·6	96·9	1235·0	95·6	1251·8
99·4	1203·9	98·1	1219·9	96·8	1236·2	95·5	1253·1
99·3	1205·1	98·0	1221·1	96·7	1237·5	95·4	1254·4
99·2	1206·4	97·9	1222·4	96·6	1238·8	65·3	1255·7
99·1	1207·6	97·8	1223·6	96·5	1240·1	95·2	1257·0
99·0	1208·8	97·7	1224·9	96·4	1241·4	95·1	1258·4
98·9	1210·0	97·6	1226·1	96·3	1242·7	95·0	1259·7
98·8	1211·2	97·5	1227·4	96·2	1244·0	94·9	1261·0

RESISTANCE IN B.A. OHMS OF A KNOT-POUND OF COPPER WIRE OF VARIOUS CONDUCTIVITIES, AT 75° FAH.

Percentage of Conductivity.	Resistance.	Percentage of Conductivity.	Resistance.	Percentage of Conductivity.	Resistance.	Percentage of Conductivity.	Resistance.
94·8	1262·4	93·6	1278·6	92·4	1294·8	91·2	1312·1
94·7	1263·7	93·5	1280·0	92·3	1296·1	91·1	1314·6
94·6	1264·0	93·4	1281·3	92·2	1297·4	91·0	1315·1
94·5	1266·4	93·3	1282·7	92·1	1298·8	90·9	1316·5
94·4	1267·7	93·2	1284·0	92·0	1300·1	90·8	1318·0
94·3	1269·1	93·1	1285·4	91·9	1301·6	90·7	1319·4
94·2	1270·4	93·0	1286·8	91·8	1303·1	90·6	1320 9
94·1	1271·8	92·9	1288·1	91·7	1304·6	90·5	1322·4
94·0	1273·1	92·8	1289·4	91·6	1306·1	90·4	1323·8
93·9	1274·5	92·7	1290·8	91·5	1307·6	90·3	1325·3
93·8	1275·8	92 6	1292·1	91·4	1309·1	90·2	1326·8
93·7	1277·2	92·5	1293·4	91·3	1310·6	90·1	1328·2

COEFFICIENTS FOR CORRECTING THE OBSERVED RESISTANCE OF PURE COPPER WIRE AT ANY TEMPERATURE TO 75° FAH.—(*Kempe.*) See p. 193.

Temperature in Degrees Fah.	Coefficient.	Temperature in Degrees Fah.	Coefficient.	Temperature in Degrees Fah.	Coefficient.	Temperature in Degrees Fah.	Coefficient.
100	·9484	91·5	·9656	83	·9832	74·5	1·0011
99·5	·9494	91	·9666	82·5	·9842	74	1·0021
99	·9504	90·5	·9677	82	·9853	73·5	1·0032
98·5	·9514	90	·9687	81·5	·9863	73	1·0042
98	·9524	89·5	·9697	81	·9874	72·5	1·0053
97·5	·9534	89	·9708	80·5	·9884	72	1·0064
97	·9544	88·5	·9718	80	·9895	71·5	1·0074
96·5	·9554	88	·9728	79·5	·9905	71	1·0085
96	·9564	87·5	·9738	79	·9916	70·5	1·0096
95·5	·9575	87	·9749	78·5	·9926	70	1·0106
95	·9585	86·5	·9759	78	·9937	69·5	1·0117
94·5	·9595	86	·9769	77·5	·9947	69	1·0128
94	·9605	85·5	·9780	77	·9958	68·5	1·0139
93·5	·9615	85	·9790	76·5	·9968	68	1·0149
93	·9626	84·5	·9801	76	·9979	67·5	1·0160
92·5	·9636	84	·9811	75·5	·9980	67	1·0171
92	·9646	83·5	·9821	75	1·0000	66·5	1·0182

COEFFICIENTS FOR CORRECTING THE OBSERVED RESISTANCE OF PURE COPPER WIRE OF ANY TEMPERATURE TO 75° FAH.—*Continued.* See p. 193.

Temperature in Degrees Fah.	Coefficient.	Temperature in Degrees Fah.	Coefficient.	Temperature in Degrees Fah.	Coefficient.	Temperature in Degrees Fah.	Coefficient.
66	1·0193	57	1·0389	48	1·0589	39	1·0793
65·5	1·0204	56·5	1·0400	47·5	1·0601	38·5	1·0804
65	1·0214	56	1·0411	47	1·0612	38	1·0816
64·5	1·0225	55·5	1·0422	46·5	1·0623	37·5	1·0828
64	1·0236	55	1·0433	46	1·0634	37	1·0839
63·5	1·0247	54·5	1·0444	45·5	1·0646	36·5	1·0851
63	1·0258	54	1·0455	45	1·0657	36	1·0862
62·5	1·0269	53·5	1·0466	44·5	1·0668	35·5	1·0873
62	1·0280	53	1·0478	44	1·0679	35	1·0885
61·5	1·0290	52·5	1·0489	43·5	1·0690	34·5	1·0896
61	1·0301	52	1·0500	43	1·0702	34	1·0908
60·5	1·0312	51·5	1·0511	42·5	1·0714	33·5	1·0920
60	1·0323	51	1·0522	42	1·0725	33	1·0932
59·5	1·0334	50·5	1·0533	41·5	1·0736	32·5	1·0943
59	1·0345	50	1·0544	41	1·0748	32	1·0954
58·5	1·0356	49·5	1·0556	40·5	1·0759	..	..
58	1·0367	49	1·0567	40	1·0771	..	..
57·5	1·0378	48·5	1·0578	39·5	1·0782	..	..

Logarithms of Coefficients for Calculating Copper Resistance at Different Temperatures Fah.* Increase 0·21 per Cent. per 1° F.

Deg.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	Deg.
32	0·03918	0·03909	0·03899	0·03890	0·03881	0·03872	0·03863	0·03854	0·03845	0·03836	32
33	·03827	·03818	·03808	·03799	·03790	·03781	·03772	·03763	·03754	·03745	33
34	·03736	·03726	·03717	·03708	·03699	·03690	·03681	·03672	·03663	·03654	34
35	·03644	·03635	·03626	·03617	·03608	·03599	·03590	·03581	·03572	·03562	35
36	·03553	·03544	·03535	·03526	·03517	·03508	·03499	·03490	·03480	·03471	36
37	·03462	·03453	·03444	·03435	·03426	·03417	·03408	·03398	·03389	·03380	37
38	·03371	·03362	·03353	·03344	·03335	·03326	·03316	·03307	·03298	·03289	38
39	·03280	·03271	·03262	·03253	·03244	·03234	·03225	·03216	·03207	·03198	39
40	·03189	·03180	·03171	·03162	·03152	·03143	·03134	·03125	·03116	·03107	40
41	·03098	·03089	·03080	·03070	·03061	·03052	·03043	·03034	·03025	·03016	41
42	·03007	·02998	·02988	·02979	·02970	·02961	·02952	·02943	·02934	·02925	42
43	·02916	·02906	·02897	·02888	·02879	·02870	·02861	·02852	·02843	02834	43
44	·02824	·02815	·02806	·02797	·02788	·02779	·02770	·02761	·02752	·02742	44
45	·02733	·02724	·02715	·02706	·02697	·02688	·02679	·02670	02660	·02651	45
46	·02642	·02633	·02624	·02615	·02606	·02597	·02588	·02578	·02569	·02560	46
47	·02551	·02542	·02533	·02524	02515	·02506	·02496	·02487	·02478	·02469	47
48	·02460	·02451	·02442	·02433	02424	·02414	·02405	·02396	·02387	·02378	48
49	·02369	·02360	·02351	·02342	·02332	·02323	·02314	·02305	·02296	·02287	49
50	·02278	·02269	·02260	·02250	·02241	·02232	·02223	·02214	·02205	·02196	50
51	·02187	·02178	·02168	·02159	·02150	·02141	·02132	·02123	·02114	02105	51
52	·02096	·02086	·02077	·02068	·02059	·02050	·02041	·02032	·02023	·02014	52
53	·02004	·01995	·01986	·01977	·01968	·01959	·01950	·01941	·01932	·01922	53

* By Clark, Forde & Taylor. For Rule and Example how to use Tables, see page 193.

LOGARITHMS OF COEFFICIENTS FOR CALCULATING COPPER RESISTANCE AT DIFFERENT TEMPERATURES FAH.* INCREASE 0·21 PER CENT. PER 1° F.—*Continued.*

Deg.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	Deg.
54	·01913	·01904	·01895	·01886	·01877	·01868	·01859	·01850	·01840	·01831	54
55	·01822	·01813	·01804	·01795	·01786	·01777	·01768	·01758	·01749	·01740	55
56	·01731	·01722	·01713	·01704	·01695	·01686	·01676	·01667	·01658	·01649	56
57	·01640	·01631	·01622	·01613	·01604	·01594	·01585	·01576	·01567	·01558	57
58	·01549	·01540	·01531	·01522	·01512	·01503	·01494	·01485	·01476	·01467	58
59	·01458	·01449	·01440	·01430	·01421	·01412	·01403	·01394	·01385	·01376	59
60	·01367	·01358	·01348	·01339	·01330	·01321	·01312	·01303	·01294	·01285	60
61	·01276	·01266	·01257	·01248	·01239	·01230	·01221	·01212	·01203	·01194	61
62	·01184	·01175	·01166	·01157	·01148	·01139	·01130	·01121	·01112	·01102	62
63	·01093	·01084	·01075	·01066	·01057	·01048	·01039	·01030	·01020	·01011	63
64	·01002	·00993	·00984	·00975	·00966	·00957	·00948	·00938	·00929	·00920	64
65	·00911	·00902	·00893	·00884	·00875	·00866	·00856	·00847	·00838	·00829	65
66	·00820	·00811	·00802	·00793	·00784	·00774	·00765	·00756	·00747	·00738	66
67	·00729	·00720	00711	·00702	·00692	·00683	·00674	·00665	·00656	·00647	67
68	·00638	·00629	00620	·00610	·00601	·00592	·00583	·00574	·00565	·00556	68
69	·00547	·00538	·00528	·00519	·00510	·00501	·00492	·00483	·00474	·00465	69
70	·00456	·00446	·00437	·00428	·00419	·00410	·00401	·00392	·00383	·00374	70
71	·00364	·00355	·00346	·00337	·00328	·00319	·00310	·00301	·00292	·00282	71
72	00273	·00264	·00255	·00246	·00237	·00228	·00219	·00210	·00200	·00191	72
73	·00182	·00173	·00164	·00155	·00146	·00137	·00128	·00118	·00109	·00100	73
74	·00091	·00082	·00073	·00064	·00055	·00046	·00036	·00027	·00018	·00009	74

* By Clark, Forde & Taylor. For Rule and Example how to use Tables, see page 193.

German Silver weighs about 530 lbs. per cubic foot, specific gravity 8·5.

A prism of German silver one metre long and one square millimetre in section weighs about 8·5 grammes, and its resistance is about 0·206 ohm at 0° C., and increases about ·04 per cent. per 1° C. The resistance of a prism of German silver one metre long, weighing one gramme, is about 1·75 ohms at 0° C.

German silver is employed generally for rheostats, resistance coils, and other parts of apparatus in which high resistance is required. It consists of—

Copper, ...	4 parts.
Nickel, ...	2 ,,
Zinc, ...	1 ,,

It possesses great permanence, and the variation in its resistance due to changes of temperature is small. Its coefficient per degree C. is 0·00044, copper being 0·0038—that is, nine times less. Its resistance per metre-gramme is 1·85 ohm, while copper is 0·144 ohm. The effect of age and of strong currents on German silver is very marked. It becomes brittle. Mr. Willoughby Smith has found a similar change in an alloy of gold and silver.

Specific Resistances.—(*J. A. Fleming.*) See p. 194*b*.

	Legal Ohms per c. Centimetre at 0° C.	Per cent. Variation of Res. 1° C. from 0° to 100° C.
Annealed copper, . .	1·624	·388
German silver, . .	20·9	·044
Platinum silver, . .	24·36	·031
Platinoid, . . .	32·8	·021
Manganese steel, . .	68 about	·122

Manganese steel contains from 10 to 20 per cent. of manganese. It is practically non-magnetic, and is recommended for parts of dynamos. According to Prof. W. F. Barrett its specific resistance at 15° C. is 75 legal microhms per c. centimetre, and its percentage variation of resistance ·136 for 1° C., through a range of 200° C. Its breaking strain is about 49 tons per sq. inch for soft wire, and 110 tons for hard; ordinary steel wire being 54 to 63 and best piano steel wire 150 tons. Its density is 7·8, that of common steel being 7·7.

Resistance of 36 Inches of German Silver Wire at 60° Fah., by Elliot Brothers.

Birmingham Wire Gauge.	Diameter.		Ohms.	Birmingham Wire Gauge.	Diameter.		Ohms.
	Inches.	Millimetres.			Inches.	Millimetres.	
4¼	·2302	5·847	·00846	21	·032	·813	·44
5	·226	5·740	·0088	21½	·03	·762	·5
6¼	·198	5·029	·01144	22	·028	·711	·574
7	·183	4·648	·0134	23½	·026	·660	·666
7½	·175	4·445	·0146	...	·024	·609	·782
8¼	·160	4·064	·01752	24	·022	·558	·931
10	·136	3·454	·02425	25	·02	·508	1·12
10½	·128	3·251	·0273	26	·018	·457	1·39
12	·107	2·717	·0393	27	·016	·406	1·76
12½	·10	2·54	·045	28	·014	·355	2·3
13	·092	2·336	·053	30	·012	·305	3·23
14¼	·08	2·032	·07	31	·01	·254	4·6
15	·07	1·778	·091	31½	·0095	·241	4·994
16	·065	1·651	·104	32	·009	·228	5·565
16½	·0625	1·587	·115	32½	·0085	·216	6·239
...	·06	1·521	·125	33	·008	·203	7·04
17	·058	1·473	·134	33½	·0075	·190	8·014
...	·056	1·422	·144	34	·007	·177	9·2
...	·054	1·371	·154	34½	·0065	·165	10·41
...	·052	1·32	·166	34½	·006	·152	12·52
18	·05	1·274	·180	...	·0055	·139	14·992
...	·048	1·219	·195	35	·005	·127	18·032
18½	·046	1·168	·213	35½	·0045	·114	22·261
...	·044	1·117	·232	36	·004	·106	28·175
19	·042	1·066	·255	...	·0035	·088	36·9
...	·04	1·016	·281	...	·003	·076	50·077
...	·038	·965	·312	...	·0025	·053	72·127
20	·036	·914	·348	...	...	...	...
	·034	·864	·386	...	...	...	...

By the Board of Trade provision under the Electric Lighting Act, 1882, the current through any main or service line shall not exceed 2000 amperes per square inch of section of a pure copper wire of equal conductivity.

This area of the conductor appears too small (see tables pp. 217–222 and p. 223).

The insulation per mile of the same lines shall not be less than 5000 ohms for every volt in the corresponding standard pressure.

Heating of conductors, Prof. G. Forbes, see p. 212

Jamieson's Rule.—For Ship Lighting Leads.

The conductor to be of the best soft copper, not less than 95°/₀ conductivity, with a cross-section not less than 1 square millimetre for every *ampere and a-half* of current passing through it (which is at the rate of about 1000 amperes to the square inch); the insulation resistance of the whole circuit, when fitted, including all switches, &c., to be not less than at the rate of ·1 megohm per lamp for every volt of E.M.F. generated by the dynamo.

N.B.—Before sending the leads for fitting into a ship, specimens of not less than 100 feet of each size used, should be immersed in salt, sea, or brine water for twenty-four hours, then carefully tested for insulation resistance, and not passed unless they give over 10 megohms. Specimen joints should be treated in the same way, and give at least 100 megohms each. Stranded conductors should be used for the larger main leads. See pp. 178, 208.

Although the above rule for the size of conductors is not strictly in accordance with theory (p. 212), or applicable to large and long district mains, it has given excellent results in the case of installations on board ship, and in houses where the maximum current conveyed by any single leading wire did not exceed 100 amperes, and the furthest lamp was not more than 100 yards from the generator. The required sizes of conductor are easily calculated or found direct from tables (pp. 208, 217, and 223–226), in which the smallest sizes for even single lamps are of sufficient strength to withstand rough handling. There is not the slightest danger from overheating in any part of the circuit, and the rule is economical when applied to the best class of insulated leads, as tested by Sir Wm. Thomson's law, p. 209.

The fall in E.M.F. is 2·5 volts for every 100 yards of conductor, and the percentage waste due to the heating of the conductor is 2·6 of the power being conveyed for every 100 yards of its length. See *Proc. Inst. C. E.*, vol. lxxix., p. 17.

SIZES OF WELL INSULATED SHIP LEADS.

In accordance with Jamieson's Rule, p. 207.

For Swan 20 c.p. or Edison 16 c.p. Lamps, allowing for a fall of 2·5 volts per 100 yards.

Maximum Number of Lamps to be carried.	For 45 to 60 Volt Lamps requiring 1·5 to 1·1 Amperes.	For 90 to 110 Volt Lamps requiring 0·8 to 0·6 Ampere.
	Board of Trade Wire-Gauge Branch Leads.	Board of Trade Wire-Gauge Branch Leads.
1	No. 18	No. 20
2	„ 16	„ 18
3	„ 14	„ 16
4	„ 14	„ 16
5	„ 12	„ 14
10	„ 10	„ 12
15	„ 8	„ 10
20	„ *6 or 7/15 strand	„ 9 or 7/16 strand
25	„ 5 „ 7/14 „	„ 8 „ 7/16 „
30	19/16 „	19/18 „
40	19/16 „	19/16 „
50	19/15 „	19/16 „
60	19/14 „	19/15 „

* Single wires larger than No. 6 gauge should not be used, owing to the difficulty in fitting them. 7/15 means 7 wires, each of No. 15 wire-gauge, twisted into a strand.

ECONOMY OF CONDUCTORS.—The heat generated represents the power wasted in the wire. It is

$$H\,P = \frac{C^2R}{746} = C^2 \times R \times \cdot 00134,$$

where C and R are the currents in amperes and resistance in ohms.

Fusing Effects of Electric Currents.

By W. H. Preece, F.R.S. See "Proc. Roy. Soc.," vol. xliv., March 15, 1888.

The Law—$C = a\,d^{3/2}$, where, C, current; a, constant; and d, diameter—is strictly followed; and the following are the final values of the constant, "a," for the different metals as determined by Mr. Preece :—

	Inches.	Centimetres.	Millimetres.		Inches.	Centimetres.	Millimetres.
Copper, . . .	10,244	2,530	80·0	Iron, . . .	3,148	777·4	24·6
Aluminium, . .	7,585	1,873	59·2	Tin, . . .	1,642	405·5	12·8
Platinum, . .	5,172	1,277	40·4	Alloy (lead and tin 2 to 1), . . .	1,318	325·5	10·3
German Silver, .	5,230	1,292	40·8	Lead, . . .	1,379	340·6	10·8
Platinoid, . .	4,750	1,173	37·1				

With these constants the two following tables have been calculated:—

Table Showing the Amperes Required to Fuse Wires of Various Sizes and Materials.

No. S.W.G.	Diameter d	$d^{3/2}$	Copper. $a = 10,244$	Aluminium $a = 7585$.	Platinum. $a = 5172$.	Ger. Silver. $a = 5230$.	Platinoid. $a = 4750$.	Iron. $a = 3148$.	Tin. $a = 1642$.	Tin-lead alloy. $a = 1318$.	Lead. $a = 1379$.
	Inches.										
14	0·080	0·022627	231·8	171·6	117·0	118·3	107·5	71·22	37·15	29·82	31·20
16	0·064	0·016191	165·8	122·8	83·73	84·68	76·90	50·96	26·58	21·34	22·32
18	0·048	0·010516	107·7	79·75	54·37	54·99	49·95	33·10	17·27	13·86	14·50
20	0·036	0·006831	69·97	51·18	35·33	35·72	32·44	21·50	11·22	9·002	9·419
22	0·028	0·004685	48·00	35·53	24·23	24·50	22·25	14·75	7·692	6·175	6·461
4	0·022	0·003263	33·43	24·75	16·88	17·06	15·50	10·27	5·357	4·300	4·499
26	0·018	0·002415	24·74	18·32	12·49	12·63	11·47	7·602	3·965	3·183	3·330
28	0·0148	0·001801	18·44	13·66	9·311	9·416	8·552	5·667	2·956	2·373	2·483
30	0·0124	0·001381	14·15	10·47	7·142	7·222	6·559	4·347	2·267	1·820	1·904
32	0·0108	0·001122	11·50	8·512	5·805	5·870	5·330	3·533	1·843	1·479	1·548

Note.—The size of "cut outs" or fuses for electric lighting circuits can be taken at once from the second table. Pure copper wire makes the best and most reliable cut out or fuse, and should never be less than 1 inch in length between the terminals to which it is fixed so as to prevent the cooling effect of the terminals.—A. J.

TABLE GIVING THE DIAMETERS OF WIRES OF VARIOUS MATERIALS WHICH WILL BE FUSED BY A CURRENT OF GIVEN STRENGTH.—*W. H. Preece, F.R.S.* $d = \left(\frac{C}{a}\right)^{2/3}$.

Current in amperes.	Diameter in Inches.								
	Copper. $a = 10{,}244$.	Aluminium $a = 7585$.	Platinum. $a = 5172$.	Ger. Silver. $a = 5200$.	Platinoid. $a = 4750$.	Iron. $a = 3148$.	Tin. $a = 1642$.	Tin-lead alloy $a = 1318$.	Lead. $a = 1379$.
1	0·0021	0·0026	0·0033	0·0033	0·0035	0·0047	0·0072	0·0083	0·0081
2	0·0034	0·0041	0·0053	0·0053	0·0056	0·0074	0·0113	0·0132	0·0128
3	0·0044	0·0054	0·0070	0·0069	0·0074	0·0097	0·0149	0·0173	0·0168
4	0·0053	0·0065	0·0084	0·0084	0·0089	0·0117	0·0181	0·0210	0·0203
5	0·0062	0·0076	0·0098	0·0097	0·0104	0·0136	0·0210	0·0243	0·0236
10	0·0098	0·0120	0·0155	0·0154	0·0164	0·0216	0·0334	0·0386	0·0375
15	0·0129	0·0158	0·0203	0·0202	0·0215	0·0283	0·0437	0·0506	0·0491
20	0·0156	0·0191	0·0246	0·0245	0·0261	0·0343	0·0529	0·0613	0·0595
25	0·0181	0·0222	0·0286	0·0284	0·0303	0·0398	0·0614	0·0711	0·0690
30	0·0205	0·0250	0·0323	0·0320	0·0342	0·0450	0·0694	0·0803	0·0779
35	0·0227	0·0277	0·0358	0·0356	0·0379	0·0498	0·0769	0·0890	0·0864
40	0·0248	0·0303	0·0391	0·0388	0·0414	0·0545	0·0840	0·0973	0·0944
45	0·0268	0·0328	0·0423	0·0420	0·0448	0·0589	0·0909	0·1052	0·1021
50	0·0288	0·0352	0·0454	0·0450	0·0480	0·0632	0·0975	0·1129	0·1095
60	0·0325	0·0397	0·0513	0·0509	0·0542	0·0714	0·1101	0·1275	0·1237
70	0·0360	0·0440	0·0568	0·0564	0·0601	0·0791	0·1220	0·1413	0·1371
80	0·0394	0·0481	0·0621	0·0616	0·0657	0·0864	0·1334	0·1544	0·1499
90	0·0426	0·0520	0·0672	0·0667	0·0711	0·0935	0·1443	0·1671	0·1621
100	0·0457	0·0558	0·0720	0·0715	0·0762	0·1003	0·1548	0·1792	0·1739
120	0·0516	0·0630	0·0814	0·0808	0·0861	0·1133	0·1748	0·2024	0·1964
140	0·0572	0·0698	0·0902	0·0895	0·0954	0·1255	0·1937	0·2243	0·2176
160	0·0625	0·0763	0·0986	0·0978	0·1043	0·1372	0·2118	0·2452	0·2379
180	0·0676	0·0826	0·1066	0·1058	0·1128	0·1484	0·2291	0·2652	0·2573
200	0·0725	0·0886	0·1144	0·1135	0·1210	0·1592	0·2457	0·2845	0·2760
225	0·0784	0·0958	0·1237	0·1228	0·1309	0·1722	0·2658	0·3077	0·2986
250	0·0841	0·1028	0·1327	0·1317	0·1404	0·1848	0·2851	0·3301	0·3203
275	0·0897	0·1095	0·1414	0·1404	0·1497	0·1969	0·3038	0·3518	0·3413
300	0·0950	0·1161	0·1498	0·1487	0·1586	0·2086	0·3220	0·3728	0·3617

$$HP = \frac{C^2 \times \cdot 0000007}{746}$$

Where C = current in amperes per square inch.
·0000007 = resistance of a cubic inch of pure copper at about 60° Fah.

Total horse-power wasted in mains, = { H P × number of cubic inches of copper in mains.

Heating of Equal Bobbins wound with Wires of different Diameter (*G. Forbes*).—The length of wire wound on bobbins of equal size is inversely proportional to the square of the diameter of the wire, and the resistance is inversely proportional to the fourth power of this diameter. With equal heating the intensity of current, C, and diameter of the wire, D, ought to satisfy the relation

$$\frac{C}{D^2} = a$$

Where a is a constant depending on the degree to which the wire is heated.

Heating of Two Similar Bobbins by a Current (*G. Forbes*).—Let C be the strength of a current traversing a given bobbin, and raising it to a certain temperature; C_1 the strength of current traversing a second similar bobbin, whose linear dimensions are n times those of the first, and the diameter of the wire n times that of the first wire. For equal heating we have

$$C_1 = n^{\frac{3}{2}} C.$$

Safety Limits.—The current in a dynamo should never be strong enough to injure the

insulation. Wires of 2 mm. diameter on machines can safely carry 5 to 6 amperes per square mm., and wires of 5 mm. diameter can carry 3 amperes per square mm. For wires enclosed in pipes where the cooling is greatly impeded, the current should not exceed 2 amperes per square mm., for a conductivity of 90 or 95 per cent.

Size of Conductors (*Prof. G. Forbes*).

Bare Overhead Wires.—The relation between the diameter of a conductor and the current it can safely carry without over-heating is

$$C^2 = D^3 t \frac{\pi^2 H}{4 R \times \cdot 24}$$

(See vol. xiii., also June, 1885, for paper by W. H. Snell, *Soc. Tel. Engs.*, and *Elect. Review*, May 5, 1883.)

Where C = Current in amperes.
D = Diameter of wire in centimetres.
t = Excess of temperature C. of wire over the air.
H = Coefficient of radiation and convection = ·0003.
R = Specific electrical resistance of material per cb. cm. at the limiting temp., p. 189.
·24 = Calories in a Joule.

Insulated Overhead Wires.—For gutta-percha and india-rubber insulation,

$$C = \sqrt{\left\{ \frac{\pi^2 k D_1^2}{\cdot 48 R} \times t \times \frac{3 D_2}{10 + 3 D_2 \log_{\epsilon} \frac{D_2}{D_1}} \right\}}$$

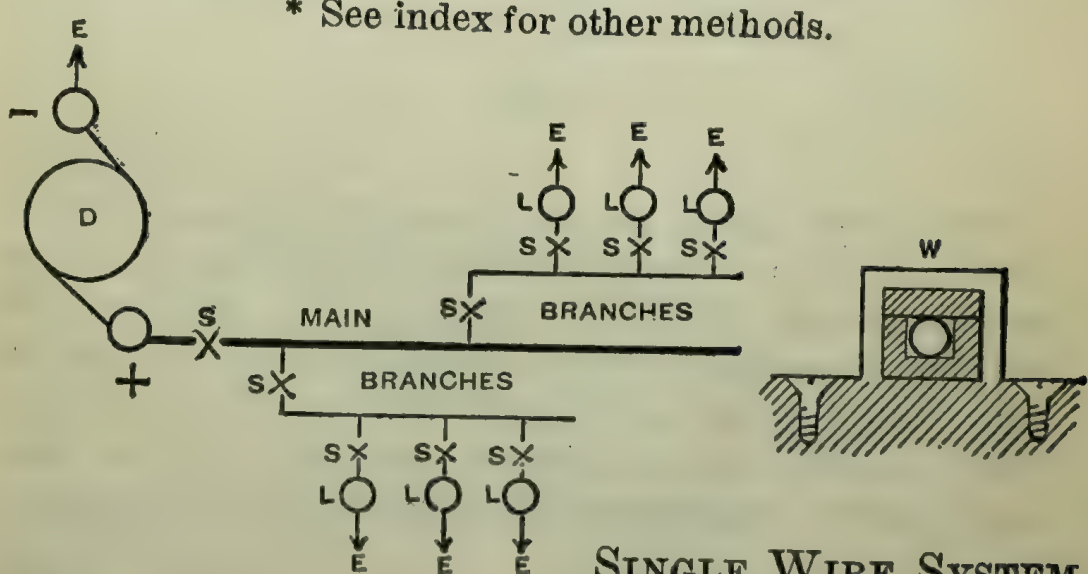
Where D_1 = Diameter of conductor.
D_2 = ,, ,, insulated cable.
t = Excess of temperature of conductor over air.
k = Heat conductivity of insulator; for G.-P = ·00048; for I.-R. = ·00041.

Coils.—For covered wires wound in coils as on dynamo magnets, permitting a rise in temperature of 50° cent. $C = \cdot 25 \sqrt{\frac{S}{\varrho}}$

Where S = Surface radiating heat.
ϱ = Resistance of the wire.

Running Leads.—Conductors for electric lighting are usually put up according to the rule, *leads left, returns right,* when they run up and down; *leads low, returns raised,* when they run along a wall. On the ground the (+) wire takes the left, the negative the right. A pocket compass shows the direction of the current.* Place your back to the dynamo or battery and look down on the compass laid beneath the wire; then if the N seeking pole of the compass be deflected towards your left hand, the current is flowing from the dynamo to you along the wire, but if to the right, the current is returning to the dynamo. Forward or (+) leads may be coloured *red* to distinguish them from return or (−) wires, which are *black* (negative colour).

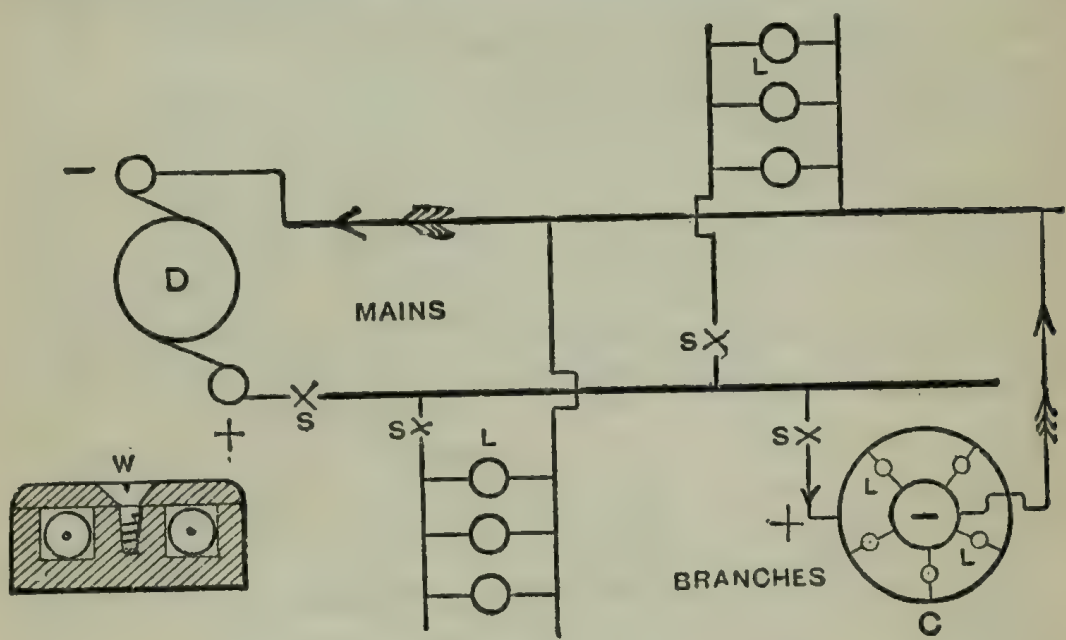
* See index for other methods.



SINGLE WIRE SYSTEM.

Index.—D, Dynamo; S, Switches and Cutouts; L, Lamps; E, Earth; W, Wooden Casing.

This system is now much used on board ship; the advantages claimed for it are, that it is less costly, more easily fitted, and offers about one-half the resistance in the leads that the double wire system does. Great care should be taken that the leads have the best insulating material (see p. 178), and that they are carefully fitted and protected from damp by being encased in dry wooden casings, such as that shown at W.



DOUBLE WIRE SYSTEM.

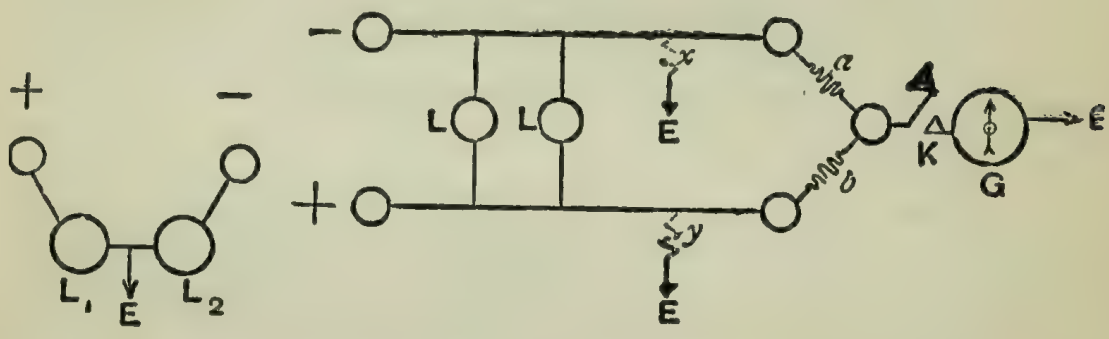
Lamps in single parallel.

Index.—D, Dynamo; S, Switches and Cutouts; L, Lamps; W, Wooden Casing.

In order to reduce the resistance of the main or the branch leads, they are sometimes joined up in the manner shown by the two circles in fig. at C, such as in the case of a saloon or room.

The advantages claimed for the "double wire system" over that of the "single wire system," or earth return, are, that a fault in one, or even

in both the insulated leads (unless very bad), does not rob the lights of current or endanger short circuiting to such an extent, and that when the machine is at work, without interfering with the work in any way, a fault may be detected and the insulation res. measured in the following manner, proposed by Dr. John Hopkinson :—



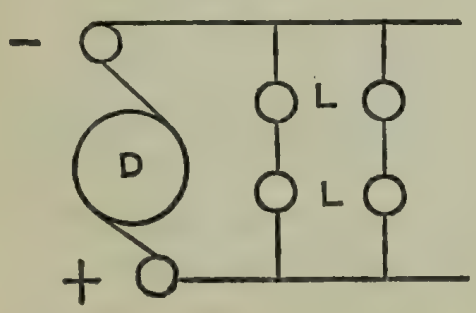
(1.) Connect, as shown in the left-hand fig., two similar lamps, L_1, L_2, between + and − leads with their junction to earth ; if there is a fault, the lamp connected to the wire in which the fault exists will be the less bright of the two. The lamps may be interchanged as a further test.

(2.) To determine the insulation res. to earth of each set of conductors, let the *conductivity* of the conductors to earth be respectively x and y, as shown in the right-hand fig. Connect the conductors by adjustable resistances, a and b, with junction to earth, as shown through a key, and a galvanometer, G. Adjust a and b until no deflection is observed on G; then $a\,x = b\,y$. Now, parallel with x or y, introduce an artificial leak to earth of *conductivity*, m, and again adjust a and b, say to a_1 and b_1, when balance obtained, $a_1\,(x + m) = b_1\,y$; whence we easily get x and y.

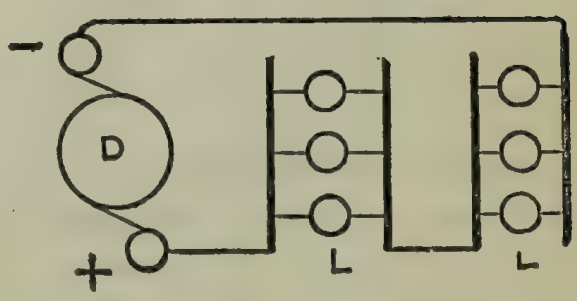
(3.) *To localise a "dead-earth" fault supposed single.*—If the wires are accessible, find the point at which the potential of the conductor when transmitting large currents, is the same as earth; if such points exist in several branches, test which is the culprit by varying current in branches. If you must work from dynamo room, measure current in conductor, C, and potential above earth, E, and let the res. of unit length of conductor be R; then fault will be at a distance $E \div C R$. If this is beyond the first branch, it can then be localised by varying the currents in the branches.

For a discussion on the relative advantages and disadvantages of the single and double wire systems, see *Electric Lighting for Steamships, Proc. Inst. C.E.*, vol. lxxix., Part I., pp. 15, 29, 35, 50, 67, 71, 85, 92.

Incandescent lamps may be joined up with two or more lamps in series. For example, if you have a 100 volt dynamo, two lamps of 50 volts each may be placed in series, or with a 150 volt dynamo, three 50 volt lamps may be placed in series, and so on, thus—

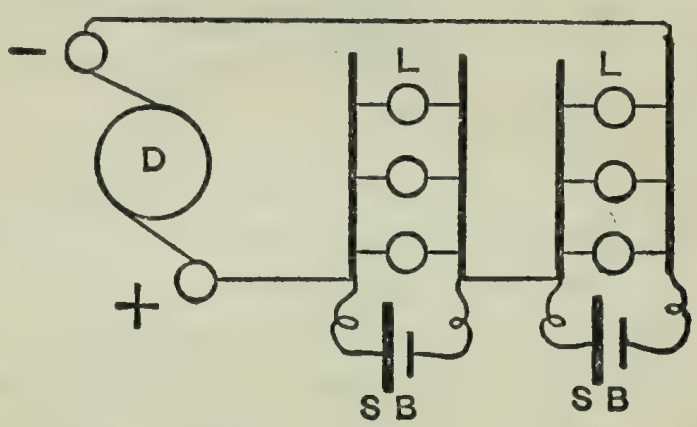


Parallel of Two or more Lamps in Series.



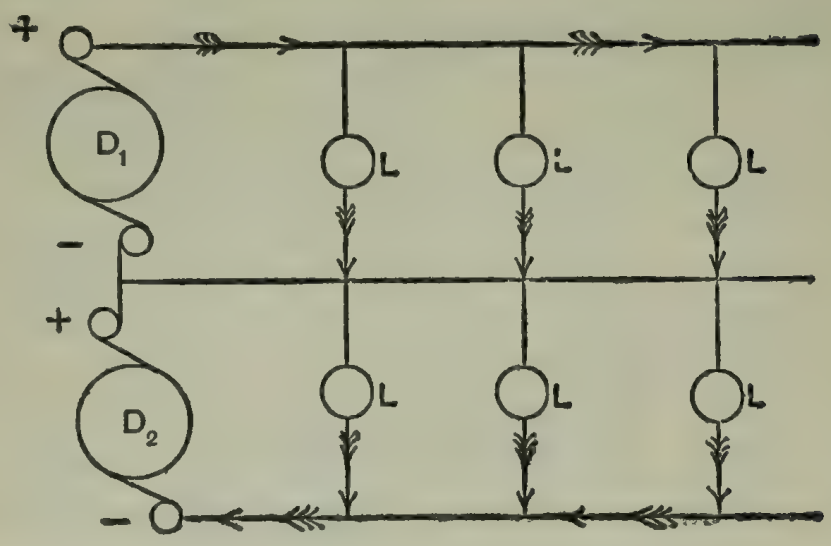
Grouping System.

The "grouping system," as adopted by the Hammond Coy. at Brighton, admits of a large number of lamps being placed in series, but it necessitates electro-magnetic devices to bring a fresh lamp or set of lamps into circuit, should any of them fail.



GROUPING SYSTEM WITH SECONDARY BATTERIES.

These electro-magnetic switches are replaced, in the case of the Colchester installation, by secondary batteries, S.B., where at first the whole of the current passes through the cells in consequence of their low res., but these soon generate a counter E.M.F., which, when it reaches that required to render the lamps incandescent, causes the whole current from the dynamo to pass through the lamps. If a lamp or lamps in any branch breaks, the excess of current passes through the battery and keeps the E.M.F. on the sides of the lamps constant. This action of secondary batteries is as valuable as their so-called storing power. See *Report to the Select Committee of the Commissioners of Sewers of the City of London*, by W. H. Preece, F.R.S.; *The Electrician*, April 18, 1885; *Electrical Review*, April 25, 1885.



EDISON-HOPKINSON THREE-WIRE SYSTEM.

When two shunt or compound dynamos are used simultaneously to feed a system of lamps, a considerable saving in return wires may be effected by adopting the above system. The series coils, as well as the shunt coils, of the two or more dynamos used with the above arrangements must each be joined in parallel. The middle conductor only carries current to or from the dynamos, when the quantity required on one side, is in excess of that on the other. See *Proc. Inst. C.E.*, vol. lxxix., p. 61—Remarks by Mr. Mordey; also Kapp, on "Electric Transmission of Energy." Whittaker & Co., pp. 211, 212.

ELECTRIC LIGHT AND POWER CONDUCTORS.

DIAMETERS, WEIGHTS, NEAREST BRITISH STANDARD WIRE GAUGE, AND RESISTANCES OF 1,000 FEET OF COPPER CONDUCTOR OF DIFFERENT SECTIONAL AREAS, WITH CURRENT IN AMPERES, AND THE CONSTANT, $C_2/746$. CONDUCTIVITY, 95 PER CENT. OF PURE COPPER. TEMPERATURE, 60° FAH.—BY E. W. BECKINGSALE, C.E.—*The Electrical Review*, Sept. 22, 1883.

Board of Trade New Legal Standard Wire Gauge		Exact Diameter.	Exact S.-Area	Weights, 1,000 Feet.		Resistance, 1,000 Feet.		Current	$C^2/746$
Nearest Nos.	Diameter. Ins.	Inches.	Sq. in.	lbs.	Tons.	Ohms.	Reciprocals.	Amperes.	
		1·1284	1·00	3854·2	1·7206	·00853	117·23	1000	1340·5
		1·0705	·90	3468·7	1·5485	·00948	105·52	900	1085·8
		1·0093	·80	3083·3	1·3765	·01066	93·789	800	857·91
		·94407	·70	2698·0	1·2044	·01218	82·065	700	656·84
		·90972	·65	2505·2	1·1184	·01312	76·203	650	566·35
		·87404	·60	2312·5	1·0324	·01422	70·341	600	482·57
		·83682	·55	2119·8	·94633	·01551	64·479	550	405·49
		·79787	·50	1927·1	·86030	·01706	58·617	500	335·12
		·77768	·475	1830·7	·81728	·01796	55·687	475	302·44
		·75694	·450	1734·4	·77427	·01896	52·756	450	271·44
		·73562	·425	1638·0	·73126	·02007	49·825	425	242·13
		·71365	·400	1541·7	·68824	·02133	46·895	400	214·48

Electric Light and Power Conductors—*Continued*, see p. 221

Board of Trade New Legal Standard Wire Gauge.		Exact Diameter.	Exact S.-Area	Weights, 1,000 Feet.		Resistance, 1,000 Feet.		Current	$C^2/746$
Nearest Nos.	Diameter. Ins.	Inches.	Sq in.	lbs.	Tons.	Ohms.	Reciprocals.	Amperes.	
		·69099	·375	1445·3	·64522	·02275	43·963	375	188·51
		·66756	·350	1349·0	·60221	02437	41·033	350	164·21
		·64328	·325	1252·6	·55919	·02625	38·102	325	141·59
		·61803	·300	1156·2	·51618	·02843	35·171	300	120·64
		·59173	·275	1059·9	·47316	·03102	32·240	275	101·37
		·56417	·250	963·54	·43015	·03412	29·308	250	83·780
		·53524	·225	867·18	·38713	·03791	26·378	225	67·861
7/0	·500	·50463	·200	770·80	·34412	·04265	23·447	200	55·619
6/0	·464	·47204	·175	674·48	·30111	·04874	20·516	175	41·053
5/0	·432	·43706	·150	578·12	·25809	·05687	17·585	150	30·161
4/0	·400	·39[illegible]94	·125	481·77	·21508	·06824	14·654	125	20·945
3/0	·372	·35682	·100	385·42	·17206	·08530	11·723	100	13·405
2/0	·348	·33851	·090	346·87	·15485	·09478	10·552	90	10·858
0	·324	·31916	·080	308·33	·13765	10662	9·3789	80	8·5791
1	·300	·29854	070	269·80	·12044	·12185	8·2065	70	6·5684
1	·300	28768	·065	250·52	·11184	·13123	7·6203	65	5·6634

ELECTRIC LIGHT AND POWER CONDUCTORS—*Continued*, see p. 221.

Board of Trade New Legal Standard Wire Gauge.		Exact Diameter.	Exact S.-Area	Weights, 1,000 Feet.		Resistance, 1,000 Feet.		Current	$C^2/746$
Nearest Nos.	Diameter. Ins.	Inches.	Sq. in.	lbs.	Tons.	Ohms.	Reciprocals.	Amperes.	
2	·276	·27640	·060	231·25	·10324	·14217	7·0341	60	4·8257
3	·252	·26462	·055	211·98	·09463	·15509	6·4479	55	4·0549
3	·252	·25232	·050	192·71	·08603	·17060	5·8617	50	3·3512
3	·252	·24592	·0475	183·07	·08173	·17958	5·5687	47·5	3·0244
3	·252	·23937	·0450	173·44	·07743	·18955	5·2756	45	2·7144
4	·232	·23262	·0425	163·80	·07313	·20070	4·9825	42·5	2·4123
4	·232	·22567	·0400	154·17	·06882	·21325	4·6895	40	2·1448
5	·212	·21851	·0375	144·53	·06452	·22746	4·3963	37·5	1·8851
5	·212	·21110	·0350	134·90	·06022	·24371	4·1033	35	1·6421
5	·212	·20342	·0325	125·26	·05592	·26246	3·8102	32·5	1·4159
6	·192	·19544	·0300	115·62	·05162	·28433	3·5171	30	1·2064
6	·192	·18712	·0275	105·99	·04732	·31018	3·2240	27·5	1·0137
7	·176	·17841	·0250	96·354	·04302	·34120	2·9308	25	·83780
7	·176	·16925	·0225	86·718	·03871	·37911	2·6378	22·5	·67861
8	·160	·15958	·0200	77·080	·03441	·42649	2·3447	20	·53619
9	·144	·14927	·0175	67·448	·03011	·48742	2·0516	17·5	·41053
9	·144	·13819	·0150	57·812	·02581	·56866	1·7585	15	·30161

ELECTRIC LIGHT AND POWER CONDUCTORS—*Continued*, see p. 221.

Board of Trade New Legal Standard Wire Gauge.		Exact Diameter.	Exact S.-Area	Weights, 1,000 Feet.		Resistance, 1,000 Feet.		Current	$C^2/746$
Nearest Nos.	Diameter Ins.	Inches.	Sq. in.	lbs.	Tons.	Ohms.	Reciprocals.	Amperes.	
10	·128	·12616	·0125	48·177	·02151	·68239	1·4654	12·5	·20945
11	·116	·11284	·0100	38·542	·01721	·85299	1·1723	10	·13405
12	·104	·10705	·0090	34·687	·01549	·94776	1·0552	9	·10858
12	·104	·10093	·0080	30·833	·01376	1·0662	·93789	8	·08579
13	·092	·09441	·0070	26·980	·01204	1·2185	·82065	7	·06568
13	·092	·08740	·0060	23·125	·01032	1·4217	·70341	6	·04825
14	·080	·07979	·0050	19·271	·00860	1·7060	·58617	5	·03351
15	·072	·07569	·0045	17·344	·00774	1·8955	·52756	4·5	·02714
15	·072	·07137	·0040	15·417	·00688	2·1325	·46895	4	·02145
16	·064	·06676	·0035	13·490	·00602	2·4371	·41033	3·5	·01642
16	·064	·06180	·0030	11·562	·00516	2·8433	·35171	3·	·01206
17	·056	·05642	·0025	9·6354	·00430	3·4119	·29308	2·5	·00838
18	·048	·05046	·0020	7·7084	·00344	4·2649	·23447	2·	·00536
19	·040	·04371	·0015	5·7812	·00258	5·6866	·17585	1·5	·00302
20	·036	·03568	·0010	3·8542	·00172	8·5299	·11723	1	·00134
21	·032	·03385	·0009	3·4687	·00155	9·4776	·10552	·9	·00109
21	·032	·03192	·0008	3·0833	·00138	10·662	·09379	·8	·00086

The Standard of Resistance for the preceding tables is ·1516 ohm, which, according to Dr. Matthiessen, is the resistance at 60° Fah. of 100 inches of pure annealed copper weighing 100 grains; 555 lbs. is taken to be the weight of one cubic foot of pure copper at 60° Fah.

The column—Current—is on the basis of 1000 amperes per square inch sectional area of the Conductor. *This rule is safe and economical for small installations.* (*See Jamieson's rule, p.* 207.)

Move the decimal point in weights columns three places to the left for the weight per foot of wire: thus, the weight of a foot of wire ·3 sec.-area is 1·156 lbs, and of No. 17 wire, ·009 lb. per foot.

From the column of Reciprocals the *combined resistance* of any strand or circuits of different sizes can readily be found by adding the reciprocals of the respective resistances and looking for the corresponding number in reciprocal column, when in the ohms column, exactly opposite will be found the approximate resistance required.

The coefficients under the constant, $C^2/746$, multiplied by the resistances, give the horse-power lost per 1,000 feet of conductor.

PERCENTAGE OF ENERGY LOST BY THE CURRENTS IN THE PRECEDING TABLES, AT DIFFERENT E.M.F.'S, THROUGH 1,000 FEET OF CONDUCTOR.

Volts.	Percentage of Energy lost.	Volts.	Percentage of Energy lost.
45	18·96	100	8·53
50	17·06	110	7·75
55	15·51	120	7·11
60	14·22	130	6·56
65	13·12	140	6·09
70	12·18	150	5·68
75	11·37	160	5·33
80	10 66	170	5 02
85	10·04	180	4·74
90	9·48	190	4·49
95	8·98	200	4·26

Dimensions of Cross Section of Round Wire, with Resistance, Conductivity, and Weight of Pure Copper Wire.

By J. T. Bottomley, M.A., F.R.S.E. (From *Electrical Review*, 3rd November, 1883).

No. on New Board of Trade wire gauge, or S.W.G.	Diameter.		* Area of cross section.	Pure Copper Wire (soft drawn) at 15° Cent. or 59° Fah.		Weight of wire Sp. gr. 8·90.
	Inch.	Centimetres.	Square Centimetres.	Resistance Ohms per metre.	Conductivity Metres per ohm.	Grms. per metre.
7/0	·500	1·270	1·267	·000135	7402·1	1127·4
6/0	·464	1·178	1·090	·000157	6370	970·2
5/0	·432	1·097	·945	·000181	5521	840·8
4/0	·400	1·016	·811	·000211	4736	721·3
3/0	·372	·945	·701	·000244	4098	624·2
2/0	·348	·884	·613	·000279	3584	545·9
0	·324	·823	·532	·000322	3107	473·2
1	·300	·762	·456	·000375	2666	406·1

* From this column the size of wire required to carry a certain current for incandescent lighting can easily be found, according to Sir William Thomson's rule for bare copper—viz., *not less* than 1 square centimetre per 50 amperes. This appears to us to be too liberal an allowance of copper for well insulated ship leads. For example, No, 20 wire of 96 per cent. conductivity will carry 1 ampere without danger of over-heating, and may be used for 1 Edison 16-candle lamp, taking ·7 amperes when length of forward and branch wires do not exceed 20 feet with perfect safety. For main leads on board ship, where the length is not great, a *safe rule* will be 1 square centimetre of 96 per cent. conductivity copper wire per 150 amperes.

DIMENSIONS OF CROSS SECTION OF ROUND WIRE, WITH RESISTANCE, CONDUCTIVITY, AND WEIGHT OF PURE COPPER WIRE—*Continued.*

No. on New Board of Trade wire gauge, or S.W.G.	Diameter.		* Area of cross section.	Pure Copper Wire (soft drawn) at 15° Cent. or 59° Fah.		Weight of wire Sp. gr. 8·90.
	Inch.	Centimetre.	Square Centimetre.	Resistance Ohms per metre.	Conductivity Metres per ohm.	Grms. per metre.
2	·276	·701	·386	·000444	2253	343·2
3	·252	·640	·322	·000532	1881	286·5
4	·232	·589	·273	·000628	1592	242·5
5	·212	·538	·228	·000751	1331	202·7
6	·192	·488	·187	·000916	1092	166·3
7	·176	·447	·157	·00109	917·8	139·8
8	·160	·406	·130	·00132	757·2	115·3
9	·144	·366	·105	·00163	614·9	93·7
10	·128	·325	·0829	·00206	484·6	73·8
11	·116	·295	·0682	·00251	398·3	60·7
12	·104	·264	·0548	·00312	320·3	48·8
13	·092	·234	·0429	·00398	250·6	38·2
14	·080	·203	·0324	·00528	189·5	28·9
15	·072	·183	·0263	·00651	153·5	23·4
16	·064	·163	·0208	·00824	121·3	18·5
17	·056	·142	·0159	·0108	92·7	14·1

DIMENSIONS OF CROSS SECTION OF ROUND WIRE, WITH RESISTANCE, CONDUCTIVITY, AND WEIGHT OF PURE COPPER WIRE—*Continued.*

No. on New Board of Trade wire gauge, or S.W.G.	Diameter.		* Area of cross section.	Pure Copper Wire (soft drawn) at 15° Cent. or 59° Fah.		Weight of wire Sp. gr. 8·90.
	Inch.	Centimetre.	Square Centimetre.	Resistance Ohms per metre	Conductivity Metres per ohm.	Grms. per metre.
18	·048	·122	·0117	0147	68·2	10·4
19	·040	·1016	·00811	·0211	47·4	7·19
20	·036	·0914	·00657	·0260	38·4	5·84
21	·032	·0813	·00519	·0330	30·3	4·62
22	·028	·0711	·00397	·0431	23·2	3·54
23	·024	·0610	·00292	·0587	17·05	2·60
24	·022	·0559	·00245	·0698	14·32	2·18
25	·020	·0508	·00203	·0845	11·84	1·80
26	·018	·0457	·00164	·104	9·59	1·46
27	·0164	·0417	·00136	·125	7·97	1·21
28	·0148	·0376	·00111	·154	6·48	0·988
29	·0136	·0345	·000937	·183	5·46	·834
30	·0124	·0315	·000779	·220	4·55	·693
31	·0116	·0295	·000682	·251	3·98	·607
32	·0108	·0274	·000591	·290	3·45	·526
33	·0100	·0254	·000507	·338	2·96	·451

DIMENSIONS OF CROSS SECTION OF ROUND WIRE, WITH RESISTANCE, CONDUCTIVITY, AND WEIGHT OF PURE COPPER WIRE—*Continued.*

No. on New Board of Trade wire gauge, or S.W.G.	Diameter.		* Area of cross section.	Pure Copper Wire (soft drawn) at 15° Cent. or 59° Fah.		Weight of wire Sp. gr. 8·90.
	Inch.	Centimetre.	Square Centimetre.	Resistance Ohms per metre.	Conductivity Metres per ohm.	Grms. per metre.
34	·0092	·0234	·000429	·398	2·51	·382
35	·0084	·0213	·000358	·478	2·09	·318
36	·0076	·0193	·000293	·585	1·71	·260
37	·0068	·0173	·000234	·730	1·37	·208
38	·0060	·0152	·000182	·943	1·06	·162
39	·0052	·0132	·000137	1·248	·801	·122
40	·0048	·0122	·000117	1·466	·682	·1038
41	·0044	·0112	·0000982	1·742	·574	·0874
42	·0040	·0102	·0000811	2·109	·474	·0721
43	·0036	·00914	·0000656	2·611	·383	·0584
44	·0032	·00813	·0000519	3·300	·303	·0462
45	·0028	·00711	·0000397	4·310	·232	·0353
46	·0024	·00610	·0000292	5·848	·171	·0260
47	·0020	·00508	·0000203	8·475	·118	·0180
48	·0016	·00406	·0000129	13·23	·076	·0115
49	·0012	·00305	·0000073	23·42	·043	·0065
50	·0010	·00254	·00000507	33·78	·030	·00451

Table Showing the Relative Dimensions of Pure Copper Wire at 60° F.

By Walter T. Glover & Co., Manchester.

B. W. G. No.	Diameter.		Area.		Weight and Length.				Length and Resistance.				Resistance & Weight.		Nearest S. W. G.*
	Inch.	Milli-metres.	Square Inches.	Square Milli-metres.	Pounds per Yard.	Pounds per 1000 ft.	Pounds per Mile. 1760 yds.	Pounds per Knot. 2029 yds.	Ohms per Yard.	Ohms per 1000 ft.	Ohms per Mile.	Ohms per Knot.	Ohms per Lb.	Lbs. per Ohm	
0000	·454	11·53	·1618	104·435	1·872	623·92	3294·3	3797·8	·000150	·050	·26	·30	·00008	12457·5	6/0
000	·425	10·79	·1419	91·52	1·640	546·76	2886·9	3328·1	·000171	·057	·30	·35	·00010	9566·7	5/0
00	·380	9·65	·1134	73·165	1·311	437·10	2307·9	2660·7	·000214	·071	·38	·43	·00016	6114·24	3/0
0	·34	8·63	·0908	58·573	1·050	349·93	1847·6	2130·0	·000268	·089	·47	·54	·00025	3918·56	2/0
1	·300	7·62	·0707	45·602	·817	272·43	1438·4	1658·3	·000344	·115	·60	·70	·00042	2375·18	1
2	·284	7·21	·0633	40·867	·732	244·15	1289·1	1486·1	·000384	·128	·67	·78	·00052	1907·59	2
3	·259	6·58	·0527	33·989	·609	203·06	1072·1	1236·0	·000462	·154	·81	·94	·00076	1319·50	3
4	·238	6·04	·0445	28·701	·514	171·46	905·3	1043·7	·000547	·182	·96	1·11	·00106	940·844	4
5	·22	5·59	·0380	24·523	·439	146·51	773·6	891·8	·000640	·213	1·13	1·30	·00145	686·911	5
6	·203	5·16	·0324	20·88	·374	124·74	658·6	759·3	·000752	·250	1·32	1·52	·00201	497·96	6
7	·18	4·57	·0254	16·417	·294	98·08	517·8	597·0	·000956	·319	1·68	1·94	·00325	307·822	7
8	·165	4·19	·0214	13·794	·247	82·41	435·1	501·6	·001137	·379	2·00	2·31	·00460	217·343	8
9	·148	3·76	·0172	11·098	·199	66·30	350·1	403·6	·001414	·471	2·49	2·87	·00711	140·689	9

* S. W. G. means the new Board of Trade or British Standard Wire Gauge, put in force March, 1884. See Index for Dimensions, &c.

Table Showing the Relative Dimensions of Pure Copper Wire at 60° F.

By Walter T. Glover & Co., Manchester.

B. W. G. No.	Diameter.		Area.		Weight and Length.				Length and Resistance.				Resistance & Weight.		Nearest S. W. G.
	Inch.	Milli-metres.	Square Inches.	Square Milli-metres.	Pounds per Yard.	Pounds per 1000 ft.	Pounds per Mile. 1760 yds.	Pounds per Knot. 2029 yds.	Ohms per Yard.	Ohms per 1000 ft.	Ohms per Mile.	Ohms per Knot.	Ohms per Lb.	Lbs. per Ohm.	
10	·134	3·40	·0141	9·098	·163	54·35	287·0	330·8	·001725	·575	3·03	3·50	·01058	94·543	10
11	·12	3·05	·0113	7·296	·131	43·59	230·1	265·3	·002151	·717	3·78	4·36	·01645	60·804	11
12	·109	2·77	·0093	6·020	·108	35·96	189·9	218·9	·002607	·869	4·59	5·29	·02416	41·392	12
13	·095	2·41	·0071	4·573	·082	27·32	144·2	166·3	·003431	1·144	6·04	6·96	·04187	23·884	13
14	·083	2·11	·0054	3·491	·062	20·85	110·1	126·9	·004495	1·498	7·91	9·12	·07186	13·916	14
15	·072	1·83	·0041	2·486	·047	15·69	82·8	95·5	·005974	1·991	10·51	12·12	·12679	7·887	15
16	·065	1·65	·0033	2·141	·038	12·79	67·5	77·8	·007330	2·443	12·90	14·87	·19104	5·234	16
17	·058	1·47	·0026	1·704	·030	10·18	53·8	62·0	·009206	3·069	16·20	18·68	·30135	3·318	17
18	·049	1·24	·0019	1·217	·022	7·27	38·4	44·2	·012898	4·299	22·70	26·17	·59157	1·690	18
19	·042	1·07	·0014	·894	·016	5·34	28·2	32·5	·017556	5·852	30·90	35·62	1·09596	·912	19
20	·035	·89	·0010	·621	·011	3·71	19·6	22·6	·025281	8·427	44·49	51·29	2·27254	·440	20
21	·032	·81	·0008	·519	·009	3·10	16·4	18·9	·030243	10·081	53·23	61·36	3·25229	·307	21

Table Showing the Relative Dimensions of Pure Copper Wire at 60° F.

By Walter T. Glover & Co., Manchester.

B. W. G. No.	Diameter.		Area.		Weight and Length.				Length and Resistance.				Resistance & Weight.		Nearest S. W. G.
	Inch.	Milli-metres.	Square Inches.	Square Milli-metres.	Pounds per Yard.	Pounds per 1000 ft.	Pounds per Mile. 1760 yds.	Pounds per Knot. 2029 yds.	Ohms per Yard.	Ohms per 1000 ft.	Ohms per Mile.	Ohms per Knot.	Ohms per Lb.	Lbs. per Ohm.	
22	·028	·71	·0006	·397	·007	2·37	12·5	14·4	·039502	13·167	69·52	80·15	5·54848	·180	22
23	·025	·63	·0005	·317	·006	1·89	10·0	11·5	·049551	16·517	87·21	100 54	8·73038	·114	23
24	·022	·56	·0004	·245	·004	1·46	7·8	8·9	·063986	21·329	112·62	129·83	14·5579	·069	24
25	·020	·51	·0003	·203	·004	1·21	6·4	7·4	·077424	25·808	136·26	157·09	21·3142	·047	25
26	·018	·46	·0002	·164	·003	·98	5·2	6·0	·095584	31·861	168·23	193·94	32·4863	·031	26
27	·016	·41	·0002	·130	·002	·77	4·1	4·7	·120974	40·325	212·91	245·46	52·0367	·019	27
28	·014	·35	·0001	·099	·002	·59	3·1	3·6	·158007	52·669	278·09	320·60	88·7724	·011	28
29	·013	·33	·0001	·086	·001	·51	2·7	3·1	·183250	61·083	322·52	371·81	119·404	·008	29
30	·012	·30	·0001	·073	·001	·43	2·3	2·6	·215065	71·688	378·51	436·37	164·462	·006	30

Pure Copper weighs 555 lbs. per cubic foot. The resistance of one mil-foot at 60° Fah. is, according to Dr. Matthiessen, 10·32311 ohms. Upon these data the above table has been calculated.

Stranded Wires.—A *Stranded Conductor* of a given length is of *greater weight* and has a *less resistance* than an equal length of the same number of wires *unstranded.*

List of Tools and Material Required for Making Joints in Electric Lighting Leads.

By India-rubber and Guttapercha Co., Silvertown.

See p. 231 for rules how to make joints.

Box with double tray, one at bottom for vice, &c., and one at top for knife, scissors, tape, &c.

2 spirit lamps.

1 stove (for heating soldering irons) or Buck & Heckman's portable soldering furnace.

1 lb. tinned binding wire, ·018 in diameter.

1 jointing vice (large).

1 flat file, 6″.

1 soldering iron (large).

1 trimming knife.

1 pair flat-nose cutting pliers, 6″.

1 pair curved scissors.

6 sheets emery cloth (medium).

4 oz. ball lamp cotton.

1 lb. solder. (See pp. 414, 415.)

$\frac{1}{4}$ lb. resin, in tin box.

$\frac{1}{2}$ lb. each of $\frac{1}{2}''$ and $\frac{5}{8}''$, No. 61, I. R., in tin case.

$\frac{1}{4}$ lb. tin of solution.

$\frac{1}{4}$ lb. $\frac{5}{8}''$ felt tape, in tin case.

$\frac{1}{2}$ lb. $\frac{5}{8}''$ twill, No. 621, for outside covering, in tin case.

1 bottle best strong varnish, with 2 brushes for outside application to joints.

1 gallon can best wood naphtha, in tin case.

1 copy of "General Instructions for Making Joints."

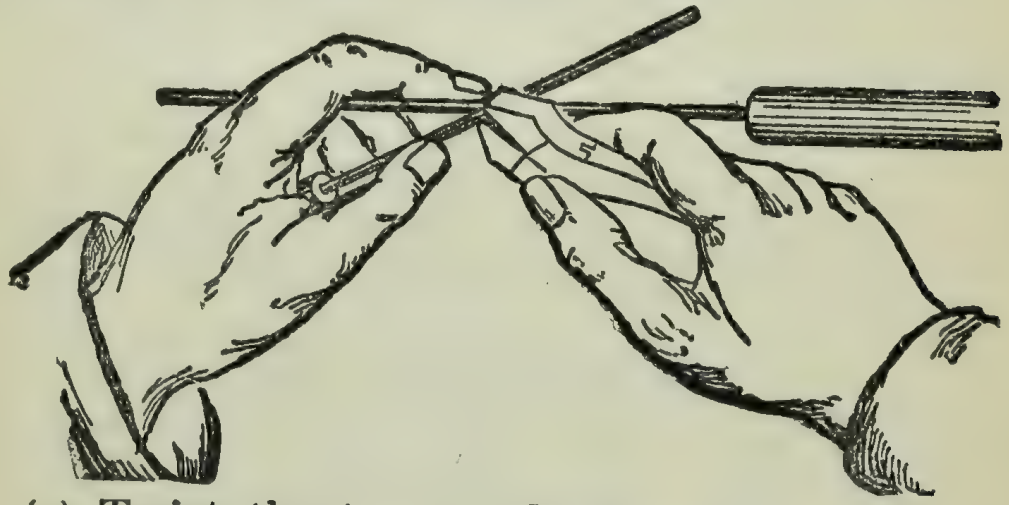
In addition to the above, the following instruments are required in separate case:—1 galvanometer detector and 1 small (chloride of silver) battery of from 4 to 6 cells.

Method of Jointing G.P.O. Guttapercha Covered Wire.

(*a*) Strip the ends which are to be jointed for about 2 inches, thus—

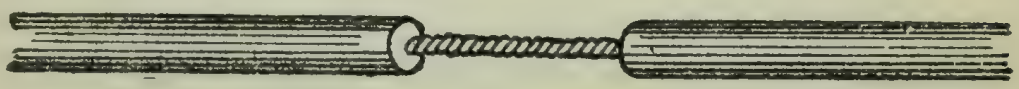
and scrape the conductors.

(*b*) Cross the conductors about ½ an inch from the G.P., and grip with the pliers.



(*c*) Twist the two conductors, first with the left hand, and then (changing over the grip of the pliers) with the right.

(*d*) Clip off the superfluous conductor and solder the twist. Then trim off the sharp ends, leaving the twist thus—

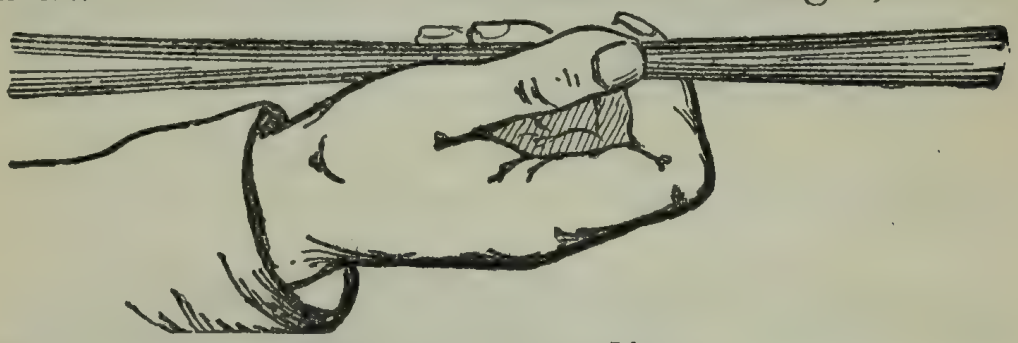


(*e*) Thoroughly clean all the rosin dirt from the conductor, and pick off all that adheres to the ends of the G.P.

(*f*) Warm up the G.P. for about 2 inches on each side of the twist, and draw down the G.P. from one side half-way over the twist, thus—

(*g*) Draw down the G.P. from the other side over the remaining portion of the twist as shown below.

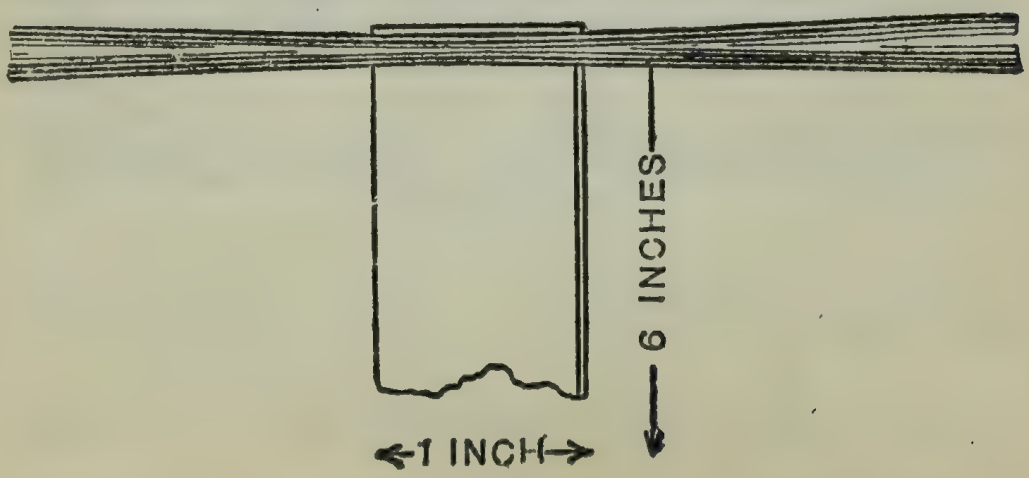
(*h*) Tool down the raised end of the second half of the draw-down over the end of the former half with a heated iron. Warm all up again with the lamp, and work round over the whole of the draw-down with the thumb and forefinger, thus—



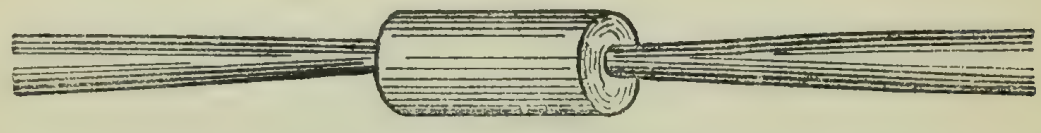
Then let it set before proceeding.

(*i*) Rough the draw-down with a knife and put on a thin coat of Chatterton's Compound for about 1 inch in the centre of the draw-down. Let it set before proceeding.

(*j*) Cut a strip of thick G.P. about 6 inches long and 1 inch wide, warm this well through from both sides with the lamp and attach one end to the centre of the draw-down, thus—



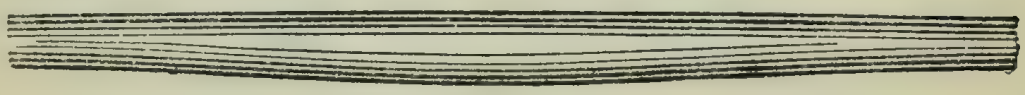
and quickly wrap it around the draw-down, giving form as shown below.



(*k*) Work the wrapping both ways quickly but carefully with finger and thumb until it extends about 4½ inches.

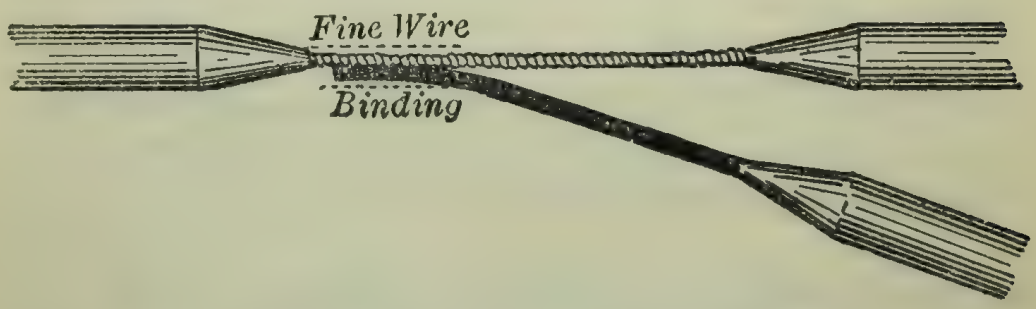
(*l*) Tool down the ends where the new G.P. meets the old; warm all up again and work with the finger and thumb as before.

(*m*) Wet and soap the hand, and rub it over the joint, leaving the finished joint smooth and round, thus—

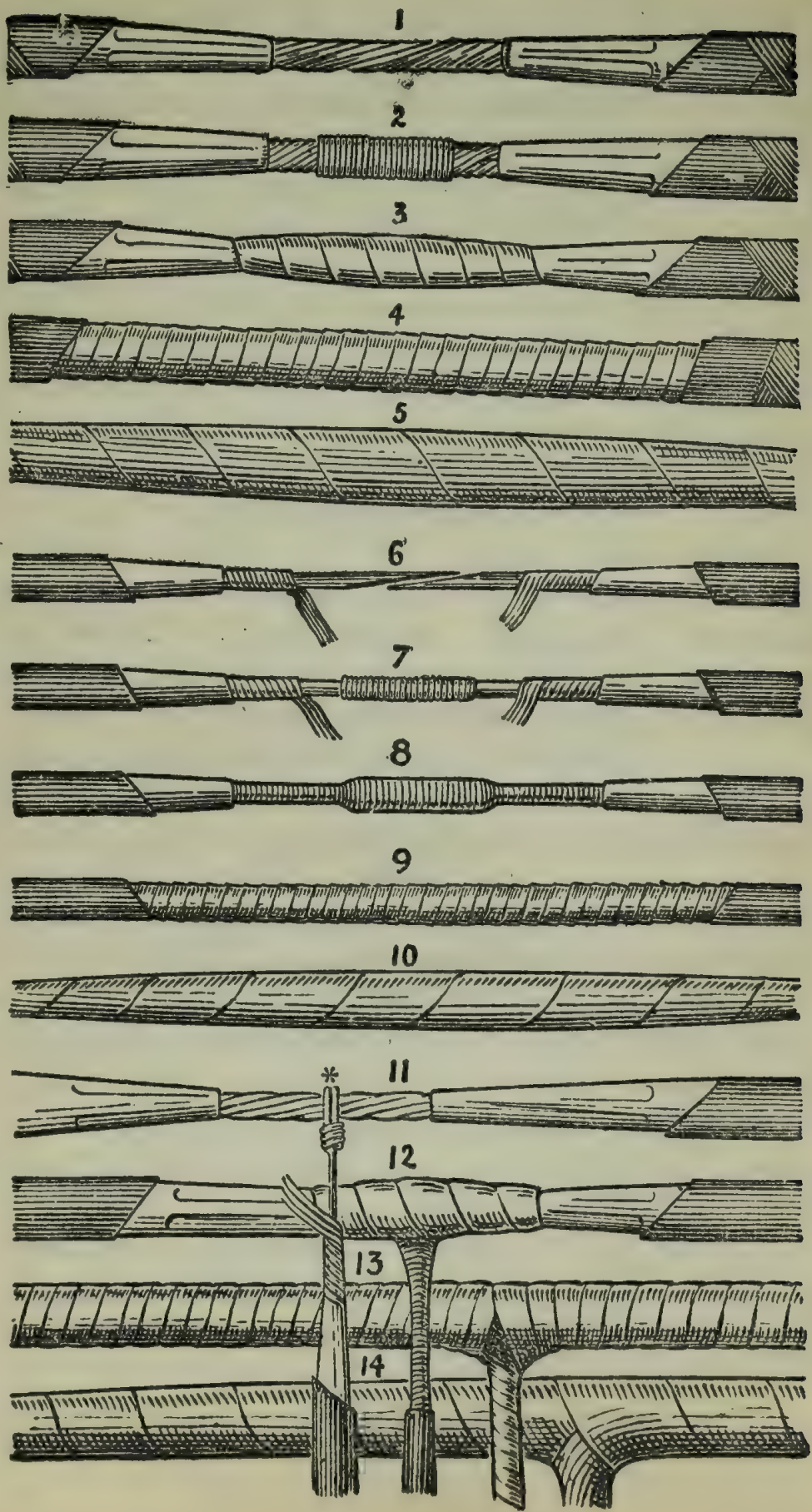


NOTE.—Cleanliness in every operation is essential to the making of a good joint.

T Joint for india-rubber, gutta-percha, or other insulated wires. This method of connecting a T lead to a main, submain, or equally small lead is preferable to that shown on the



next page, because the jointed wire is not nearly so stiff and liable to break near the soldered part.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Joints in The India-Rubber and Gutta-Percha Company's, Silvertown, Electric Lighting Leading Wires. See p. 230.

See Index for jointing too's.

Directions for making Joints in Main Conductors for Arc or Incandescent Lighting.

Preparing Ends.—Remove the two outside tapes, for about five inches from each of the ends intended to be jointed. Bare the conductor of its covering of india-rubber and inside lapping of tape for about 1½ inches, and clean the wires with emery cloth. See fig. 1.

Metal Joint.—Solder together the wires composing the strand for about an inch, and scarf the two ends with a fine file, as in fig. 1.

Bring the two scarfed ends together and solder them; if this is carefully done, the conductor will be of uniform size. Over the joint bind spirally a fine copper wire, and solder the whole together, as in fig. 2. *Resin must always be used for soldering, and not acid.*

Insulating Joint.—Taper each end with a sharp jointer's knife for 1½ inches from the conductor to the outside of the india-rubber.

Cover the metal joint with one lap of ⅝-inch broad india-rubber coated cotton tape, as in fig. 3.

Over the cotton tape, lap spirally pure india-rubber strip, ¾-inch broad, stretching it at the same time, and building up the joint by a series of coverings in alternate directions to the same size as the india-rubber coating of the wire, or slightly larger, to allow for the thickness of binding wire as in fig. 4, page 230. A very small portion of india-rubber solution should be

applied over each coat, and sufficient time allowed for the spirit to evaporate, before putting on another coat; this will cause the india-rubber to unite together.

Outer Protection.—Two coverings of prepared tapes ($\frac{5}{8}$-inch broad) are to be laid on in opposite directions with strong shellac varnish between them, and then outside another covering of waterproof tape, and finally varnished over all, as in fig. 5.

N.B.—Care must be taken to keep the hands, tools, and materials clean and dry.

Directions for making Joints in Branch Conductors for Incandescent Lighting.

Preparing Ends.—Remove the braiding, tape, and india-rubber for about four inches from each end intended to be jointed. Unlap the cotton serving next the conductor for about $1\frac{1}{2}$ inches (do not cut it off).

Metal Joint.—Thoroughly clean the ends of the wire with fine emery cloth, and scarf them with a fine file, as in fig. 6.

Bring the two scarfed ends together and solder them. If this is carefully done, the conductor will be of uniform size. Over the joint bind spirally a fine copper wire, and solder the whole together as in fig. 7, p. 230. *Resin must always be used for soldering, and not acid.*

Insulating Joint.—Cover the metal joint evenly and as thinly as possible with the cotton which has been previously unwound from the ends, as in fig. 8.

Over the cotton covering lap spirally pure

india-rubber tape ($\frac{5}{8}$-inch broad), stretching it at the same time, and building up the joint by a series of coverings in alternate directions to the same size as the india-rubber covering of the wire, or slightly larger, to allow for the thickness of binding wire, as in fig. 9, page 230. A very small portion of india-rubber solution should be applied over each coat, and sufficient time allowed for the spirit to evaporate before putting on another coat; this will cause the india-rubber to unite together.

Outer Protection.—Two coverings of felt tape ($\frac{5}{8}$-inch broad) are to be laid on in opposite directions with strong shellac varnish between them, and finally varnished over all (see fig. 10).

N.B.—Care must be taken to keep the hands, tools, and materials clean and dry.

Instructions for making T Joints in Electric Light main Conductors for Incandescent Branching.

Preparing Ends.—Remove the two outside tapes for about 5 inches from the main lead. Bare the conductor of its covering of india-rubber and inside lapping of tape for $1\frac{1}{2}$ inches.

Remove the braiding and tape for 6 inches from the end of the wire intended to be jointed to the main lead. The two rubber coverings and cotton serving are then to be unlapped for 3 inches, and the india-rubber cut off; the cotton being left on to serve over the metal joint. Thoroughly clean the strand, and also the solid wire with fine emery cloth.

Metal Joint.—Solder the wires composing the strand together, take two or three turns of the

solid wire round the main conductor, and back round itself for three or more turns, and solder *only* at the *, as in fig. 11, p. 230. *Resin must always be used for soldering, and not acid.*

Insulating Joint.—Taper each end of the main lead with a sharp jointer's knife for 1½ inches from the conductor to the outside of india-rubber, re-cover the solid wire with the cotton up to and round its junction with the main lead. Cover the metal joint with one lap of india-rubber coated cotton tape, as in fig. 12.

Lap spirally pure india-rubber strip (⅝-inch broad) stretching it at the same time, commencing at the india-rubber covering of the solid wire, lapping up to and round the junction and up to the india-rubber covering at either end of the main lead, putting on a series of coverings in alternate directions until the joint is slightly larger than the india-rubber covering on the main lead, and tapered from the junction to the same size as the india-rubber coating of the solid wire, as in fig. 13.

A very small portion of india-rubber solution should be applied over each coat and sufficient time allowed for the spirit to evaporate before putting on another coat; this will cause the india-rubber to unite together.

Outer Protection.—Two coverings of prepared tape (⅝-inch broad) are to be laid on in opposite directions with strong shellac varnish between them, and then outside another covering of waterproof tape, and finally varnished over all, as in fig. 14.

Care must be taken to keep the hands, tools, and materials clean and dry.

AERIAL LINES.

Iron weighs about 480 lbs. per cubic foot, specific gravity 7·7; a cubic inch weighs 0·28 lbs.

The **weight** of any iron wire per statute mile is $\frac{d^2}{72}$ lbs.

The weight of iron per knot in any submarine cable is about $\frac{d^2n}{6806}$ cwts. where d = diameter of wire in mils. and n = number of wires.

The **resistance** of a prism of soft iron 1 metre long and 1 square mm. in section is about 0·096 ohm at 0° C., and increases about ·39 per cent. for 1° F., or ·7 per cent. for 1° C.

The **resistance** per statute mile of a galvanised iron wire is about $\frac{360{,}000}{d^2}$ ohms at 60° Fah., or about seven times that of pure copper.

Standard wires.—The American standard is the ohm-mile—that is, the weight of a cylindrical wire one mile in length, giving a resistance of one ohm at 60° Fah., and has been adopted by the British Post Office. The ohm-mile of pure copper would be 891·5 lbs. at 60° Fah. The ohm-mile of pure iron would be 3,996 lbs. While the first iron wire supplied under this specification gave an ohm-mile of 5,500 lbs., it is now frequently obtained as low as 4,520 lbs. In the present specification of the Post Office the fixed maximum resistance is equivalent to an ohm-mile of 4,800 lbs. at 60° Fah. of Swedish charcoal iron.

Analysis of Samples of Annealed Iron Wire.

By W. H. Preece, F.R.S.

No. 1. Swedish Charcoal Iron, very soft and pure.
„ 2. Swedish Charcoal Iron, good for P. O. specification.
„ 3. Swedish Charcoal Iron, not suited for P. O. specification.
„ 4. Swedish Siemens-Martin Steel, 0·10 carbon.
No. 5. Best Puddled Iron.
„ 6. Bessemer Steel, special soft quality, 0·15 carbon.
„ 7. Bessemer Steel, special hard quality, 0·45 carbon.
„ 8. Best Cast Steel.

No. of Samples.	1	2	3	4	5	6	7	8
Carbon,	0·09	0·10	0·15	0·10	0·10	0·15	0·44	0·62
Silicon,	trace	trace	0·018	trace	0·09	0·018	0·028	0·06
Sulphur,	trace	0·022	0·019	0·035	0·03	0·092	0·126	0·074
Phosphorus,	0·012	0·045	0·058	0·034	0·218	0·077	0·103	0·051
Manganese,	0·06	0·03	0·234	0·324	0·234	0·72	1·296	1·584
Copper,	trace	trace	trace	trace	0·015	trace	trace	trace
Iron,	99·69	99·70	99·44	99·60	99·11	98·74	98·20	97·41
Ohm-mile at 60° Fah.,	lbs. 4,546	lbs. 4,502	lbs 4,820	lbs. 5,308	lbs. 5,974	lbs. 6,163	lbs. 7,468	lbs. 8,033

This Table shows in a very striking way that the electrical conductivity of iron wire increases with the percentage of pure iron, except where the percentage of manganese is high; an increase in the percentage of manganese augments the electrical resistance considerably more than an increase in the percentage of sulphur or phosphorus.

Mechanical and Electrical Tests of Seven Descriptions of Iron Telegraph Wire.

By W. H. Preece, M.I.C.E., F.R.S. Four samples of each kind.

Description.	Diameter.	Twists in 6 inches.	Elongation.	Breaking Weight	Resistance per Mile reduced to 0·171 inch at 60° Fah., or 400 lbs. per Mile.†
	Inches.		Per cent.	lbs.	
"B B" puddled iron, . .	·1745	16	17½	1,470	14·4200
	·1765	13	11½	1,380	13·5592
	·165	14	15½	1,436	13 8897
	·1735	17½	14	1,182	13·8983
"B B" piled iron, all puddled, ...	·171	16	17	1,220	14·0582
	·1645	9	13	1,316	15·5820
	·1645	12	11½	1,238	15 6234
	·1725	17½	16½	1,292	14 1640
'Extra B B." Box piled of puddled and English charcoal, thus— E. C. / P P P P P P / E. C. *	·168	11	14½	1,456	15 6191
	·174	10½	15	1,538	15·3715
	·1695	11½	16	1,398	15·5452
	·172	12	14½	1,452	15·3017

* E. C. = English charcoal. P = puddled iron.
† Standard size used in United Kingdom and abroad.

MECHANICAL AND ELECTRICAL TESTS OF SEVEN DESCRIPTIONS OF IRON TELEGRAPH WIRE—*Continued.*

Description.	Diameter.	Twists in 6 inches.	Elongation.	Breaking Weight.	Resistance per Mile reduced to 0·171 inch at 60° Fah., or 400 lbs. per Mile.†
	Inches.		Per cent.	lbs.	
"Extra special B B." Four-sided charcoal-piled English charcoal, and puddled thus— E. C. / E. C. | P | P / P | P | E. C. / E. C.	·172	15	15	1,420	15·5129
	·1685	14	14½	1,412	15·6844
	·172	10½	14	1,484	16·3574
	·172	15	16	1,478	15·5471
English Bessemer (known as homogeneous iron), .	·1715	20	16	1,634	15·9988
	·169	19	13½	2,118	18 5663
	·170	19½	17½	1,484	14·6922
	·1687	12	14	2,548	19·1480
Swedish Bessemer, . . .	·1735	21	17	1,392	12·6808
	·1745	20½	12	1,380	12·9709
	·1735	22	18	1,456	13·6587
	·1715	13½	17½	1,318	13 0222
Swedish charcoal, ...	·171	23	13½	1,191	11·3490
	·1695	25	10	1,358	11·3052
	·1695	24½	13½	1,194	11·2241
	·1715	27½	13	1,128	11·3133

Galvanising.—The durability of iron wire is maintained by galvanising. The wire, which is first chemically cleaned by passing through a bath of hydrochloric acid, is then drawn through a bath of molten zinc, at such a pace as will secure the adhesion of the requisite layer of zinc. The zinc becomes oxidised when exposed to the air, and since zinc oxide is insoluble in water, the wire is protected with an impervious coating; but when this zinc oxide is exposed to sulphur acids or salt spray, it becomes converted into zinc sulphate or chloride, which are soluble. Hence the zinc is removed, the iron is exposed, and oxidation begins.

When the galvanised wire is to be suspended in smoky districts, it is additionally protected by a braided covering, well tarred. In some countries galvanising is not resorted to, but simple oiling with boiled linseed oil. In this climate galvanising is imperative.

Testing Iron Wire for Aerial Lines.—The operation of testing is a most important one, and requisite not only for the user, but also for the manufacturer. Flaws, impurities, faults, notwithstanding the greatest care, will occur, and they can only be detected by the most rigid examination and tests. Tests are mechanical and electrical. The mechanical tests are for breaking-stress, elongation, and resistance to torsion. For hard steel wire, in place of the torsion test it is usual to specify that the wire shall bear wrapping round its own diameter and unwrapping without breaking. In France the torsion test is replaced by another by which the wire is bent at a right angle backwards and forwards four

times for wire 4 mm. in diameter. The electrical test is simply that for resistance—$\frac{1}{30}$ of a mile of the wire to be examined is wound round a dry wooden drum; and its electrical resistance is taken in ohms by means of a Wheatstone bridge. Galvanising is tested by dipping in sulphate of copper, and by bending or rolling round a bar of varying diameter, according to the size of the wire.

The Post Office authorities have abandoned a gauge as applied to wires, and defined the size by diameter and weight. All copper wires are known by their diameters in "mils," or thousandths of an inch, and all iron wires by their weights in lbs. per mile. The table, pp. 237, 250, give the iron wires in general use.

GOVERNMENT OF INDIA. SPECIFICATION OF GALVANISED IRON TELEGRAPH WIRES FOR LINES AND CABLES.

1. In this specification Whitworth's decimal gauge will be used for gauging the wire, but the weight per mile is to be the only standard of size recognised in the contract.

2. The accompanying tables give the data for inspection as regards limits of size, weight, tensile strength, ductility, &c., for all sizes of telegraph wires for the Indian Government.

3. The calculated diameters of the wires are entered in the table, for aiding in the inspection, but, in the event of any dispute, the weight of 10 feet (or the $\frac{1}{528}$ part of a mile) is to be taken as giving the correct size of the wire.

4. The wire is to be highly annealed, smoothly galvanised, free from scales, inequalities, all imperfections, flaws, sand splits, and other defects, and to be cylindrical. Each piece must be warranted not to contain any weld whatever, either in the rod before being drawn, or in the wire afterwards.

5. A sample coil of the size of wire, for which a Tender may be submitted, in every respect equal to this Specification, is to be supplied by the Contractor within 14 days of the acceptance of his Tender.

6. Every coil of the supply is to be gauged for diameter, in one or more places, with Whitworth's decimal gauge, and from a number (not exceeding five per cent. of the total quantity) 10-feet pieces are to be cut and weighed. As a rule these pieces will be taken from the coils cut for the tests mentioned in para. 7.

7. Every coil of the supply may be tested for tensile strength and ductility, and five per cent. of the entire number of coils may be cut and tested in any part. Coils cut for this purpose, or for weighing samples, are not to be welded or jointed together again, but the separate pieces are first to be bound in separate coils, and then the two bound together to form a coil of the standard size (so that they may either be conveniently jointed on the work before being paid out, or that broken coils may be chosen for short lengths when required).

8. Tests for tensile strength are to be made by the direct appliance of weight vertically. No hydraulic machine or lever is to be used.

The wire is at first to lift a weight equal at

least to $\frac{9}{10}$ of the minimum tensile strength entered in the table for the size under trial, and the remaining tenth is to be added gradually, by convenient ordinary weights of not less than $\frac{1}{5}$ of the remainder, or $\frac{1}{50}$ of the minimum tensile strength. No less weight than $\frac{1}{100}$ of the minimum will be reckoned.

9. Tests for ductility will be made as follows: —The piece of wire will be gripped by two vices, and twisted. The twists to be reckoned by means of an ink spiral formed on the wire during torsion. The full number of twists must be distinctly visible between the vices, no fractions being reckoned. In sizes above 150 lbs. per mile, the vices will be six inches apart; but in those of 150 lbs. or less, they will be three inches apart, and the number of twists entered in the table have been reckoned proportionately.

10. All wire, after it has been accepted and weighed, is to be dipped into boiled linseed oil, at a temperature of not less than 100° Fah., and Tenders are to state separately the price of the "iron wire" and the charge for oiling it.

11. It is desired to obtain the wire in coils, all of one piece, of the size entered in the table. If this cannot be undertaken, the Contractor may tender for the supply of wire with two pieces only to the coil, joined either by Ryland's patent joint, or left unjointed and packed as stated in para. 7. No piece weighing less than one-third the minimum weight of a coil will be accepted. In Cable Wires these joints will not be allowed.

12. The Supervisor of Telegraph Stores and the Examiners appointed by the India Store

Department may be present during the whole process of making the wire, and they shall have every facility accorded to them by the manufacturer for seeing the wire during all stages of its manufacture.

13. They shall be at liberty to see all billets or bars before rolling, and to weigh any after rolling, in order to satisfy themselves that the separate pieces are of the full weights contracted to be delivered without joint. They shall also be at liberty to examine all wire after drawing, and before galvanising, to see that no welds exist.

14. The testing shall be performed by the Examiners, or under their direction, and the Contractor must supply all the necessary machinery, apparatus, convenience, labour, and assistance of every kind required for the purpose without making any claim or charge for the same, it being distinctly understood that these expenses are included in the prices stated in the Tender. Waste of all kinds in testing to be at the expense of the Contractor. All testing apparatus, &c., to be immediately under the control of the Supervisor of Telegraph Stores, and the Examiners serving under his directions, during the period of examination.

15. Every coil is to be weighed separately, and the weight stamped on a metallic label, which is to be firmly fixed to the inner part of each coil by a piece of iron wire of not less size than 60 lbs. per mile. Each coil will likewise be sealed with a leaden disc, which will bear the examination mark. All labels and discs to be provided by the Contractor, free of expense.

The form of both to be decided on by the Supervisor of Telegraph Stores.

16. The wire to be coiled carefully, so as to resemble newly drawn wire as much as possible, and each coil to be securely bound with four separate binders of galvanised iron wire of strong quality, and of not less size than 150 lbs., nor greater than 600 lbs. per mile. For the sake of distinction the binders of Cable Wires are to be ungalvanised.

17. Proper accommodation must be provided by the Contractor for the storage of approved, and the distinct and safe custody of rejected, wire, until finally disposed of, under the control of the Supervisor of Telegraph Stores, and the Examiners of the department.*

GERALD C. TALBOT,
Director-General of Stores.

India Office.

Hard-drawn **Copper Wire** is now coming into use for long and important aerial lines, owing to its greater conductivity and less electro-static capacity for the same conductivity and position as an iron wire. See Mr. Preece's paper in the *British Association Report* for 1885, or *The Electrician*, Sept. 18, 1885; also page 256 this book.

* See Index for Tables or Wire for India Government Cables and Land Lines.

Line Wire for Government of India.

Table of Weights and Tests for Standard Sizes.

(See Index for Specification.)

Nominal Size.	Diameter.			Weight per Mile.			Weight of 10 Feet.		
	Required.	Allowed.		Required.	Allowed.		Required.	Allowed.	
		Minimum.	Maximum.		Minimum.	Maximum.		Minimum.	Maximum.
	Inches.	Inches.	Inches.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
3½	·2547	·251	·258	900	886·5	913·5	1·704	1·682	1·726
4½	·2325	·229	·236	750	738·7	761·3	1·420	1·399	1·441
5	·2205	·217	·223	675	665	685	1·278	1·260	1·296
5½	·2079	·204	·210	600	591	609	1·136	1·119	1·153
9½	·1470	·144	·150	300	294	306	·568	·556	·680
12½	·1039	·102	·106	150	147	153	·284	·278	·290
15½	0735	·072	·075	75	73·5	76·5	·142	·139	·145
16	·0657	·065	·067	60	58·8	61·2	·113	·112	·114

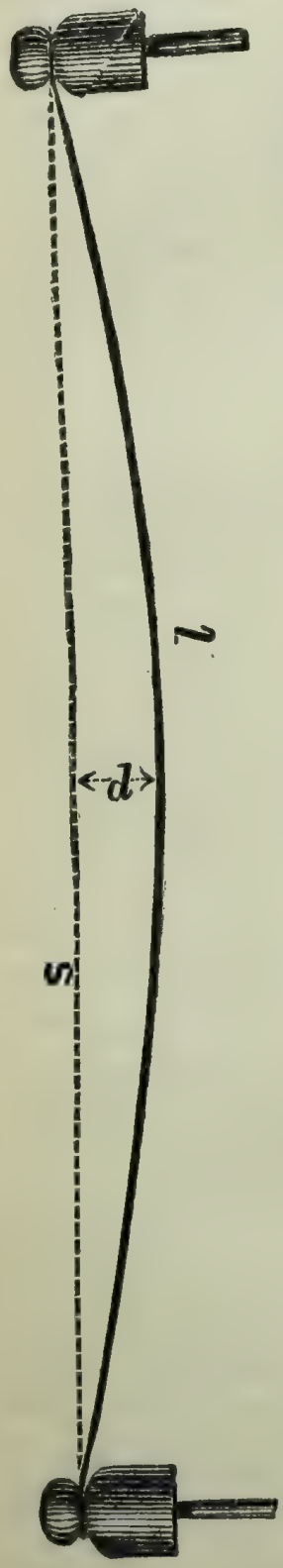
Table of Weights and Tests for Standard Sizes—*Continued.*

Tests for Strength and Ductility.										Weight of each Coil.	
To bear	Twists. *	To bear	Twists *	To bear	Twists. *	To bear	Twists. *	To bear	Twists *	Minimum.	Maximum.
Lbs.		Lbs.		Lbs.		Lbs.		Lbs.		Lbs.	Lbs.
2,775	14	2,850	13	2,925	12	3,000	11	3,076	10	95	105
2,312	15	2,375	14	2,437	13	2,500	12	2,562	11	95	105
2,081	16	2,137	15	2,193	14	2,250	13	2,306	12	95	105
1,850	17	1,900	16	1,950	15	2,000	14	2,050	13	95	105
925	24	950	22	975	21	1,000	19	1,025	18	70	80
462	17	475	16	487	15	500	14	512	13	70	80
208	24	214	23	219	21	225	19	231	18	35	40
167	26	171	25	176	23	180	22	185	20	35	40

Note.—It will be seen that the following manufacturing margins are allowed, viz.:—For wire weighing 600 lbs. per mile and upwards, $1\frac{1}{2}$ per cent. in size, and for wire of less than 600 lbs., 2 per cent. in size. The tests for tensile strength and ductility are strictly in proportion to the size of the wire, except in the two smaller sizes, where the tensile strength is reduced 10 per cent. on account of the disproportionate amount of zinc.

In sizes above 150 lbs. per mile the vices will be six inches apart, but in those of 150 lbs. or less, they will be three inches apart, and the number of twists entered are calculated proportionately.

Dip and Span Tables for Telegraph Wires.
By R. Von Fischer-Treuenfeld.



A telegraph wire suspended between two supports of equal height forms a curved line, "the catenary," depending upon the following conditions :—

S = span, or direct distance between the two supports.
l = actual length of wire between the two supports.
d = dip of wire.
W = weight of 1 foot of wire.
b = tension of wire at the lowest point of the curve.

The mathematical deduction of these unknown quantities is to be found in many text-books of telegraphy, and the following equations only relate to the practical calculation of dip and span, viz. :—

(1.) $$d = \frac{W \,.\, S^2}{8 \,.\, b}$$

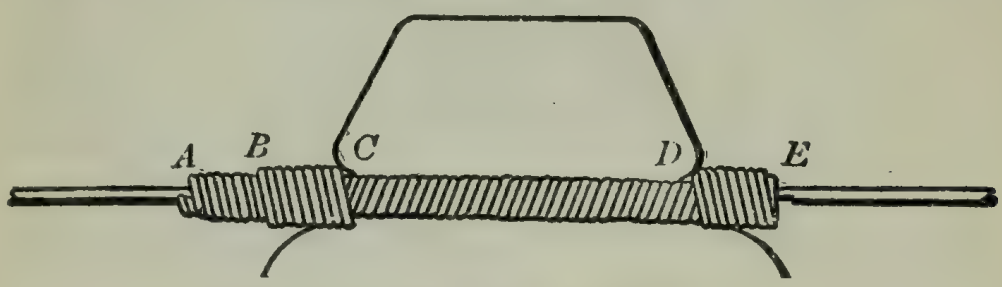
(2.) $$l = S + \frac{8 \,.\, d^2}{3 \,.\, S}$$

(3.) $$d = \sqrt{\frac{3S\,(l - S)}{8}}$$

The table, see p. 249, is so arranged

that the dip required for any span between 200 and 2000 feet can be read off without calculation. A change of temperature causes either an increase or decrease in the length, l, of the wire, the dip, d, and the tension, b. The table gives the necessary allowance which must be made for any decrease of temperature after the day of the erection of any given span. The wire must be erected under the following conditions, viz.: —That after it has contracted to its minimum of length, under the action of the lowest temperature of the coldest winter day, the limit of tension, b, which represents a certain fraction of the breaking strain, must not be exceeded.

This fraction is generally one-third the actual breaking strain; and taking for illustration the P.O. standard wire, No. 8 B.W.G., of ·170-inch diameter, with a weight of 396 lbs. per statute mile, and 1200 lbs. actual minimum breaking strain, the maximum tension, b, of the suspended wire, during its lowest winter temperature, ought not to exceed $b = 400$ lbs. The weight of 1 foot of this wire is $W = 0{\cdot}075$ lb.



METHOD OF BINDING COPPER WIRE.

Two wires are whipped round the line wire from B to E, thence back to D, then from the *upper* side of the line wire they are taken round the neck of the insulator to the *under* side of the line wire at C, back over the first layer to B. and then taken on as a single layer to A. The length of wire required for each binder is :—For 150 lbs. line wire, 52 inches; for 100 lbs. line wire, 40 inches. The binding wire weighs 50 lbs. per mile, and is No. 17½ B.W.G.

DIP AND SPAN TABLE FOR AERIAL WIRES AT ALL TEMPERATURES AND IN ALL COUNTRIES.—*Treuenfeld.*

Wire when at lowest probable Temperature.			Length of Wires and Dip at Temperatures above the lowest probable Temperatures.									
			10° C. above.		20° C. above.		30° C. above.		40° C. above.		50° C. above.	
Span in Feet.	Length in Feet.	Dip in Feet.	Length.	Dip.	Length.	Dip.	Length.	Dip.	Length.	Dip.	Length.	Dip.
200	200·012	0·94	200·037	1·67	200·059	2·10	200·087	2·55	200·112	2·90	200·137	3·20
300	300·039	2·10	300·076	2·92	300·114	3·58	300·150	4·11	300·187	4·58	300·224	5·02
400	400·096	3·75	400·149	4·73	400·198	5·45	400·255	6·18	400·308	6·80	400·361	7·36
500	500·181	5·86	500·241	6·72	500·303	7·54	500·361	8·23	500·421	8·88	500·481	9·49
600	600·317	8·44	600·394	9·41	600·468	10·27	600·548	11·11	600·625	11·85	600·702	12·57
700	700·512	11·49	700·596	12·51	700·672	13·28	700·764	14·16	700·848	14·92	700·932	15·64
800	800·750	15·00	800·848	15·95	800·947	16·86	801·044	17·70	801·142	18·51	801·240	19·30
900	901·067	18·98	901·178	19·94	901·292	20·84	901·340	21·27	901·511	22·58	901·622	23·40
1000	1001·460	23·43	1001·583	24·36	1001·746	25·59	1001·829	26·19	1001·952	27·06	1002·075	27·90
1100	1101·949	28·36	1102·086	29·33	1102·221	30·27	1102·360	31·20	1102·497	32·09	1102·634	32·96
1200	1202·531	33·75	1202·678	34·72	1202·796	35·47	1202·972	36·57	1203·119	37·46	1203·266	38·21
1300	1303·216	39·61	1303·380	40·59	1303·521	41·43	1303·708	42·52	1303·872	43·45	1304·036	44·36
1400	1404·020	45·94	1404·193	46·92	1404·365	47·87	1404·539	48·82	1404·712	49·74	1404·885	50·64
1500	1504·945	52·73	1505·135	53·82	1505·320	54·70	1505·515	55·69	1505·705	56·65	1505·895	57·58
1600	1606·000	60·00	1606·197	60·98	1606·395	61·94	1606·591	62·89	1606·788	63·82	1606·985	64·74
1700	1707·194	67·73	1707·400	68·68	1707·606	69·63	1707·812	70·53	1708·012	71·04	1708·224	71·99
1800	1808·534	75·93	1808·752	76·86	1808·970	77·81	1809·188	78·75	1809·406	79·68	1809·624	80·59
1900	1910·045	84·60	1910·275	85·56	1910·505	86·51	1910·735	87·45	1910·965	88·39	1911·195	89·31
2000	2011·719	93·75	2011·967	94·74	2012·215	95·71	2012·463	96·68	2012·711	97·64	2012·959	98·59

Iron Wire for Land Line.

Birmingham Wire Gauge.	Diameter.		Area of Section.	Weight of 100 yards.	Weight of 1 mile.	Length of 1 cwt.	Breaking Strain.	
							Hard Wire.	Soft Wire.
	Ins.	Mms.	Sq in	lbs.	lbs.	yds.	lbs.	lbs.
00	0·363	9·21	0·103	102·00	1794	110	8600	6000
0	0·331	8·40	0·086	84·72	1490	132	7100	4750
1	0·300	7·61	0·071	68·75	1210	162	6000	4000
2	0·280	7·11	0·062	59·90	1054	187	4850	3400
3	0·260	6·60	0·053	51·65	909	215	4000	2900
4	0·240	6·10	0·045	44·00	775	255	3400	2500
5	0·220	5·59	0·038	37·00	651	303	2950	2200
6	0·200	5·08	0·031	30·56	538	361	2500	1800
7	0·185	4·69	0·0265	26·15	461	428	2200	1520
8	0·170	4·31	0·023	22·10	389	509	1750	1200
9	0·155	3·93	0·0195	18·36	323	609	1500	950
10	0·140	3·55	0·016	14·97	264	747	1200	820
11	0·125	3·17	0·0125	11·95	211	939	820	650
12	0·110	2·79	0·010	9·24	163	1244	710	510
13	0·095	2·41	0·0071	7·05	124	1589	640	400
14	0·085	2·15	0·0057	5·51	97	2031	510	350
15	0·075	1·92	0·0044	4·29	76	2608	410	300
16	0·065	1·65	0·0033	3·22	57	3473	350	200
17	0·057	1·44	0·0026	2·48	44	4515	280	150
18	0·050	1·27	0·0020	1·91	34	5600	200	115
19	0·045	1·14	0·0016	1·55	27	7246	150	85
20	0·040	1·01	0·0013	1·22	21	9168	110	65
21	0·035	0·88	0·0010	0·94	17	11980	85	50
22	0·030	0·76	0·0007	0·69	12	16300	65	40

The above table has been supplied by Messrs. Johnson and Nephew, of Manchester; the *soft* wire is that manufactured by them expressly for telegraphic purposes.

Birmingham Wire Gauge.—The diameters of the several gauges must be considered approximate only. There is no authorised standard, and the sizes of different makers vary considerably. See Index for S.W.G., or new Board of Trade wire gauge.

TELEPHONE CONSTRUCTION.

By T. Fletcher, M.Inst.E.E.

The conducting wires used for telephonic circuits are either iron, silicious bronze, or hard-drawn copper for bare wires; and copper, coated with guttapercha or india-rubber, for covered wires and cables.

The relative resistances of these materials for wires of *equal diameter* may be taken approximately as

Copper, ...	1
Silicious bronze, . . .	2 to 3
Iron, ...	5 to 6

For the *same metal*, or for the *same quality* of any given metal, the weight per unit of length in pounds multiplied by the resistance of that unit in ohms, is a constant quantity. Thus the constant for iron wire to the English Post Office, and to the Indian Government specification, is $W \times R = 5{,}400$. W being the weight in lbs. per mile, and R the resistance in ohms per mile, at 60° F.

All iron wire for conductors should be made from best charcoal puddled bars. Stay wires should be of homogeneous or steely iron.

Single wire (or "solid," as it is usually termed) is used for road lines. "Strand" wire (three single wires twisted together) is usually employed for over-house lines, as it is less "musical" and more easily handled.

The subjoined specifications are those now issued by the United Telephone Company (of London), and are found amply sufficient.

The electrical test should not be taken on a shorter length than 17·6 yards.

All tests of iron wire should be made *after* the wire has been "killed" (*i.e.*, stretched).

Specification for Galvanised Iron Telephone Wire.

Note.—In the following Specification, the term "piece" shall be understood to mean a single length of wire without weld, joint, or splice of any description, and a "coil" shall be held to mean a "piece" of wire in the form of a coil; a "parcel" of wire shall be any quantity of manufactured wire delivered at any one time.

1. The wire must comply with the conditions and tests specified or provided for in the table herewith.

2. The wire is to be uniformly annealed, soft and pliable, free from scale, irregularities, flaws, splits, and other defects, and must be uniformly cylindrical.

3. The wire is to be drawn in continuous pieces of the weights given in the table. Each piece must be warranted not to contain any weld, joint, or splice whatever, either in the rod before it is drawn, or in the finished wire. The coils to be properly bound within the limits of weight shown in the table.

4. The wire is to be well galvanized, and this will be tested by taking samples from any coil or coils, and plunging them into a solution of Sulphate of Copper (saturated at 60° Fahrenheit), and allowing them to remain in the solution for one minute, when they are to be withdrawn and wiped clean.

The galvanizing shall admit of this process being four times performed with each sample, without there being any sign of a reddish deposit of Metallic Copper on the wire.

5. Samples taken from the coils shall bear bending round bars of the following diameters, without any signs appearing of the Zinc cracking or pealing off.

For No.	8	gauge,	a bar	2	inches	in diameter.
,,	11	,,	,,	$1\frac{1}{2}$	,,	,,
,,	14	,,	,,	$\frac{3}{4}$	,,	,,
,,	16	,,	,,	$\frac{1}{4}$	,,	,,

6. After having been galvanized, the wire is to be sufficiently stretched or straightened to remove all bends or sinuosities by passing round drums either varying in diameter, or differently geared as to speed.

7. The electrical resistance of the wire is not to exceed the limit shown in the table, the resistance of each test piece being reduced according to its diameter and weight.

8. Any wire which exceeds the limits given in the accompanying table, or fails in any way to comply with the specified trials may be rejected, and if more than 20 per cent. of any parcel of wire fails in this respect, the whole of such parcel may be rejected without further examination.

9. Every bundle of wire after it has been bound, is to be dipped in boiled linseed oil, at a temperature of not less than 100° Fahrenheit, and the prices stated in the tender, for all gauges, are to include the value of this process.

10. All strand wire must be laid up with right-handed lay.

TABLE REFERRED TO IN FOREGOING SPECIFICATION—CONDUCTIVITY WIRE.

Nominal Size, S.W.G.	Diameters.			Weight per Mile.			Minimum Breaking Strain for Standard Weight.	Minimum Number of Twists.	Maximum Resistance per mile of Standard Weight at 60 deg. F.	Constant = Weight × Resistance.	Minimum Weight of each Piece or Coil.	Maximum Weight of each Bundle.
	Standard.	Minimum.	Maximum.	Standard.	Minimum.	Maximum.						
	Mils.	Mils.	Mils.	Lbs.	Lbs.	Lbs.	Lbs.	In 6 inches.	Ohms.		Lbs.	Lbs.
8	170	165	175	400	376	423	1069	20	12	4800	90	120
11	120	116	124	200	186	212	535	30	24	4800	90	112
								In 3 inches.				
16	66	63	69	60	55	66	160	20	...	...	20	112
3/16	66 each.	63 each.	69 each	180	165	198	480	20 each.	30	5400	112	140

STAY WIRE.

Nominal Size, S.W.G.	Diameters.			Weight per Mile.			Minimum Breaking Strain for Standard Weight.	Minimum Number of Twists.	Minimum Weight of each Piece or Coil.	Maximum Weight of each Bundle.
	Standard.	Minimum.	Maximum.	Standard.	Minimum.	Maximum.				
	Mils.	Mils.	Mils.	Lbs.	Lbs.	Lbs.	Lbs.	In 6 inches.	Lbs.	Lbs.
8	170	165	175	400	376	423	1425	20	90	120
11	120	116	124	200	186	212	713	25	50	112
	Of any single wire.			Of any single wire.						
7/11	120	116	124	1400	1302	1484	4991	25 each	112	120
								In 3 inches.		
5/16	66	63	69	60	55	66	1069	17 each.	112	140
7/16	66	63	69	60	165	198	1496	17 each.	112	140
7/14	81	78	84	90	84	95	2245	12 each.	112	140

NOTE.—The weight per mile is regarded as the only standard, and upon this the other calculations are based.
—*January*, 1889.

E H Waldo

Specification for Hard Drawn Copper Wire.

General Conditions.—The wire must comply with the conditions and tests hereinafter specified, or provided for in the table given herewith, and any wire which fails in so doing may be rejected. If more than 10 per cent. of any parcel of wire fails in these respects, the whole of such parcel may be rejected without further examination; and should any wire be so rejected, no part of it shall be remade and presented for testing.

The wire to be uniformly cylindrical and free from irregularities, scores, flaws, splits, and other defects.

Torsion Test.—The number of turns specified for each size of wire is intended as a minimum only. It is highly desirable that the wire should show a uniform and considerable increase on the minimum. Preference will be given to wire which does so.

Lay.—The lay of all stranded wires to be right-handed and uniform, the pitch to be 2 inches for No. 18 wire.

Joints and Lengths.—No joints or splices of any kind to be made. No piece of wire to be less than 880 yards in length, nor more than 1,000 yards. This clause to apply equally both to single and stranded wire.

Testing.—Details of the various electrical and mechanical tests which the wire will be required to pass are given in the table annexed.

Delivery.—Single wire to be delivered in continuous coils of unbroken length.

Stranded wire, to be wound on drums to pattern, about ½ cwt. on each drum. The tare to be stamped on a lead label affixed to each drum.

Packing.—Canvas to be wound round the outside of each drum or coil, and the various drums or coils to be further packed in cases, to prevent injury during transit.

Elongation.—The elongation must not exceed 1½ per cent.

Wrapping Test.—All wire must bear wrapping in six turns round its own diameter, unwrapping and wrapping on again without breaking.—*January*, 1889.

Specification for $\frac{3}{18}$ Bronze Wire.

General Conditions.—The wire must comply with the conditions and tests hereinafter specified or provided for, and any wire which fails in so doing may be rejected, and if more than 20 per cent. of any parcel of wire fails in

TABLE FOR HARD-DRAWN COPPER WIRE (p. 254).

Nominal Size, S.W.G.	Diameters.			Weight per Mile.			Minimum Breaking Strain for Standard Weight.	Minimum Number of Twists in 3 ins.	Resistance per mile of Standard Weight at 60° F.
	Standard.	Minimum.	Maximum.	Standard.	Minimum.	Maximum.			
	Mils.	Mils.	Mils.	Lbs.	Lbs.	Lbs.	Lbs.		
12½	97	95	99	150	144	157	462	10	5·94
14	79	78	80	100	97	102	308	16	8·92
16	66	65	67	70	68	72	216	20	12·74
18	50	49	51	40	38	42	123	25	22·29

these respects, the whole of such parcel may be rejected without further examination, and should any wire be so rejected, no part shall be re-made and presented for testing. It must be uniformly cylindrical and free from flaws, scores, irregularities, splits, and other defects. No joints or splices of any kind to be made by manufacturers.

Diameter.—Minimum 49 mils. Maximum 51 mils.

Breaking Strain.—Minimum 540 lbs.

Torsion.—Minimum 20 twists in 3 inches for each strand. It is, however, highly desirable that the wire should show a material and uniform increase on this number, and preference will be given to wire which does so.

Weight.—Minimum weight per mile for each strand, 38 lbs. Maximum 42 lbs.

Resistance.—The resistance of the stranded wire shall not be more than 20 ohms per statute mile at 60° F.

Length.—No piece to be under 880 yards, nor more than 1,000 yards.

Lay —To be right-handed and uniform, the pitch to be 2 inches.

Delivery.—To be wound on drums to pattern, about ½ cwt. on each drum. The tare to be stamped on a lead label affixed to each drum.

Packing.—Canvas to be wound round the outside of each drum or coil, and the various drums or coils to be further packed in cases to prevent injury during transit.

—*January*, 1889.

Specification for No. 7½ G. P. Wire.

Conductor.—To consist of one copper wire of 49½ to 50½ mils diameter, weighing 40 lbs. per statute mile.

Electrical Resistance.—Electrical resistance not to exceed 23·5 ohms per statute mile, at 75° F.

Dielectric.—To consist of a double coating of best gutta-percha, accurately centred round the conductor, weighing about 50 lbs. per statute mile, and having an external diameter not less than 172 nor more than 176 mils.

Inductive Capacity.—The inductive capacity of the completed wire not to exceed ·290 microfarad per statute mile.

Insulation Resistance.—The insulation resistance, after one minute's electrification, to be not less than 500 megohms nor more than 1,500 megohms per statute mile.

Outer Covering.—To consist of a strand of cotton laid longitudinally, and thoroughly covering the G. P., the whole to be enclosed in a braided flax covering to pattern, and thoroughly saturated with ozokerit compound; or,

To consist of a stout, twill, selvege-edged tape, of the best quality, $\frac{5}{8}$ of an inch broad, the strength and closeness of the web being of great importance. The tape to be prepared with a thick coating of ozokerit compound, and to be wound on G. P. with a lap of not less than $\frac{3}{16}$ of an inch.

Samples of the tape intended to be used, both plain and compound, to be submitted for approval with quotation.

Coils.—The wire to be made up in continuous coils of 1,760 yards each.

Testing, &c.—The coils shall have been immersed in water at 75° F., for a period of not less than twenty-four hours, previous to being tested by the representative of the Company.

The whole to be approved by the Company's representative before delivery.

Inspection.—The Company's representative to be allowed to inspect the wire during the various stages of manufacture. —*January*, 1889.

Specification for Galvanized Tubular Iron Poles.

The poles to be of two sizes only, with an inside diameter of $2\frac{1}{2}$ ins. and $3\frac{1}{8}$ ins. respectively; the number and various lengths of each according to the Company's requirements; and the whole consignment to be delivered free to the Company's Stores.

The iron to be of good quality, free from scale and blisters, and capable of resisting a tensile strain of 20 tons per square inch of section.

The tubes to be of a uniform thickness of $\frac{1}{4}$ in. throughout their length, weighing not less than 7·2 lbs. per foot run in the case of those with an inside diameter of $2\frac{1}{2}$ ins. and 8·85 lbs. per foot run in the case of those with an inside diameter of $3\frac{1}{8}$ ins.

Each length to be straight and true longitudinally, and of true circular form throughout, properly and securely welded up.

A $\frac{1}{4}$ in. collar, $1\frac{1}{2}$ in. deep, to be shrunk on one end of each of the larger tubes, fitted close to the end, and made perfectly fast and secure. The smaller sized tubes will be required to telescope into the larger ones for a length of 2 feet from the collar.

All the tubes to be well and properly galvanized.

Should any of the tubes fail to stand the tests imposed on them in accordance with this Specification, the Company reserve to themselves the right to return the whole consignment.—*January*, 1889.

Specification for Creosoted Poles.

Poles to be of Norwegian or Swedish red fir, sound hard grown (*i.e.*, well-hearted, and with the annular rings

SIZES OF LIGHT POLES.				SIZES OF STOUT POLES.			
Length in Feet.	Diameter at Top. Inches.		Minimum Diameter at 5 feet from Butt end.	Length in Feet.	Diameter at Top. Inches.		Minimum Diameter at 5 feet from Butt end.
	Min.	Max.			Min.	Max.	
			Inches.				Inches.
24	5	5¾	7	24	5½	6¾	8
26	5	6	7¼	26	5¾	7	8¼
28	5	6¼	7¾	28	6	7¼	8¾
30	5	6¼	8	30	6	7¼	9
32	5¼	6½	8¼	32	6¼	7½	9¼
34	5¼	6¾	8¾	34	6¼	7¾	9¾
36	5½	7	9	36	6½	7¾	10
38	5½	7	9¼	38	6½	7¾	10¼
40	5½	7¼	9¾	40	6½	8	10¾
45	5¾	7½	10½	45	6¾	8½	11½
50	6	7¾	11¼	50	7	8¾	12¼
55	6	8	12	55	7¼	9	13
60	6	8	12½	60	7½	9	13½

closely pitched), straight, free from large or dead knots and other defects, and to have the bark completely removed.

Each pole to contain the natural butt of the tree, which shall be sawn square after being felled.

No timber to be cut or trimmed away from the butt end so as to reduce its natural size.

The dimensions of the poles to be in accordance with the tables given herewith.

Each pole to be well and properly creosoted with not less than 10 lbs. of creosote oil per cubic foot of timber, and all sap and moisture to be removed previous to this being applied.

The poles to be supplied as required in quantities of not less than within notice, at any time or times within the next ensuing six months, no carriage being charged for delivery to any railway goods station within 12 miles radius of the General Post Office.

The Company, however, reserve to themselves the right to take no more than 75 per cent. of the total amount tendered for, should they find this amount sufficient for their requirements.

An invoice to be sent on day following delivery, together with charges for carriage, if any, and a monthly account to be rendered in addition. A delivery note in all cases to accompany poles.—*January*, 1889.

Specification for Larch Poles.

Poles to be all of good sound English larch, the grain close and hard, the annular rings closely pitched, and the heart sound and firm. To be straight and well grown throughout their length, free from all large knots or shakes, and to have the bark completely removed.

Each pole to contain the natural butt of the tree, which must be sawn square after being felled, no timber being trimmed away from the butt end so as to reduce its natural size.

The poles must all be free from sap, no timber being supplied except such as has been felled during the winter months.

All poles to be well charred and tarred for a distance from the base varying with size of pole in accordance with table, unless otherwise specified.

The dimensions of the poles to be in accordance with the

table given herewith. All such as do not fill the requirements of this specification will be rejected.

Suppliers to keep always in stock at their yard not less than 10 per cent. of the full number of the various sizes specified, in order to ensure prompt delivery, and no carriage to be charged for delivery within a radius of 12 miles from suppliers' yard at unless a smaller quantity than three poles be required in one load, in which case a small charge to cover the extra expense of carriage will be allowed.

The poles to be supplied as required upon twenty-four hours' notice at any time or times within the next ensuing twelve months, the company, however, reserving to themselves the right to take no more than 75 per cent. of the total amount tendered for, should they find this amount sufficient for their requirements.

An invoice to be sent on day following delivery, together with charges for carriage, if any, and a monthly account to be rendered in addition.

A delivery note in all cases to accompany poles.

Length.	Minimum Diameter at Head.	Minimum Diameter 5 ft. from Butt.	Length of Charred Portion.
Ft.	In.	In.	Ft.
30	5	9	6
36	5½	10	6
40	5½	10¾	7
45	5¾	11½	7
50	6	12¼	7
55	6	13	7
60	6	13½	8
65	6½	14	8
70	6½	14½	8

Other sizes in proportion.—*January*, 1889.

Specification for Guttapercha Covered Wire.

1. The *conductor* to consist of one copper wire of $49\frac{1}{2}$ to $50\frac{1}{2}$ mils. diameter, weighing 40 lbs. per statute mile. Electrical resistance not to exceed 23·5 ohms. per statute mile, at 75° F.

2. The *dielectric* to consist of a double coating of best guttapercha accurately centred round the conductor, weighing about 50 lbs. per statute mile, and having an external diameter not less than 172, nor more than 176 mils.

3. The *inductive capacity* of the completed wire not to exceed ·290 microfarad per statute mile.

4. The *insulation resistance*, after one minute's electrification, to be not less than 500 megohms, nor more than 1,500 megohms, per statute mile.

5. The *outer covering* to consist of a strong, twill selvage-edged tape of the best quality, $\frac{5}{8}$ of an inch broad, the strength and closeness of the web being of great importance. The tape to be prepared with a thick coating of ozokerit compound, and to be wound on the guttapercha with a lap of not less than $\frac{3}{16}$ inch.

6. The wire to be made up in continuous coils of 1,760 yards each.

7. The coils shall have been immersed in water at 75° F. for a period of not less than twenty-four hours previous to being tested by the representative of the Company. The whole to be approved by the Company's representative before delivery.

8. Samples of the tape intended to be used—both plain and compounded—to be submitted for approval, *with quotation.*

9. The compounding of the tape to be effected by steeping it in a melted compound, of which ozokerit forms the largest ingredient. It is very important that the tape should adhere well to the guttapercha, but, at the same time, when pulled off by force, it should come away as cleanly as possible. The Company's representative to be allowed to inspect the wire during the various stages of manufacture.

Underground Wires in Pipes.

The wire usually employed is that known as No. 7½ "prepared"—*i.e.*, a copper wire of No. 16 gauge covered to No. 7½ gauge with guttapercha, and served with tarred and sanded tape.

A 1-inch	pipe	will	take	from	1 to	8	wires.
,, 1½	,,	,,	,,		9 to	16	,,
,, 2	,,	,,	,,		17 to	24	,,
,, 2½	,,	,,	,,		25 to	48	,,
,, 3	,,	,,	,,		49 to	72	,,
,, 4	,,	,,	,,		73 to	128	,,

Weight of Pipes.

Let D = external diameter in inches.
d = internal ,, ,,
w = weight per lineal foot in lbs.
k = constant for material.

Then

$$w = k\,(D^2 - d^2).$$

	k.
For cast-iron	= 2·45
,, wrought-iron	= 2·64
,, brass	= 2·82
,, copper	= 3·03
,, lead	= 3·86

GUTTAPERCHA.

The **specific gravity** of guttapercha is between 0·9693 and 0·981.

One cubic foot weighs between 60·56 and 61·32 lbs.; therefore, one cubic inch weighs between 0·560 and 0·567 ounce.

Guttapercha softens at 115° Fah., becomes plastic at 120°, melts at 212°. When exposed to the air, particularly at temperatures between 70° and 90° Fah., it oxidises, becomes brittle, shrinks, and cracks.

This is very noticeable in guttapercha leads, used at telegraph offices in tropical climates.

Exposure to light hastens oxidation.

Oxidation and decay are hindered by serving guttapercha core with tape soaked in Stockholm tar; but the natural acid of the tar *must first* be removed, otherwise the insulation will be reduced. Guttapercha leads encased in lead tubing remain perfect for years. No deterioration is observable in guttapercha if kept *continually* under water.

Stretched guttapercha, as used for core, resists a stress of 1000 lbs. per square inch before permanent elongation takes place, and breaks at about 3500 lbs. per square inch. Stretching increases the tenacity of guttapercha in the direction stretched.

The **weight** of guttapercha per knot in any core is $\frac{D^2 - d^2}{491}$, where D = diameter of guttapercha, and d = diameter of copper (both in mils).

The **exterior diameter** of any guttapercha core

$$= \sqrt{70{\cdot}4\,w + 491\,W} \text{ mils,}$$

where w is the weight in lbs. per knot of copper strand, and W that of the guttapercha. With a solid conductor the diameter

$$= \sqrt{55\,w + 491\,W} \text{ mils.}$$

The **insulation-resistance** per knot of a guttapercha core of the best quality = 769 (log. D − log. d) megohms at 75° Fah., after one minute's electrification.

Resistance and pressure.—The resistance of ordinary guttapercha under pressure increases in the following ratio:— *

If R be the resistance at atmospheric pressure, the resistance under the pressure, p, lbs. per square inch = $R(1 + 0{\cdot}00023\,p)$.

Resistance and temperature.—The resistance of ordinary guttapercha diminishes as the temperature increases:— *

Let R = resistance at the lower temperature;
r = resistance at the higher temperature;
t = the difference of temperature in degrees Fah.

Then, approximately, for ordinary guttapercha,

$$\log. R = \log. r - t \log. 0{\cdot}9399,$$

$$\text{and } \log. r = \log. R + t \log. 0{\cdot}9399.$$

* The resistance of guttapercha also varies with its age. When a submarine cable is laid in deep water, the insulation is greatly improved, owing to the pressure of the water and lower temperature.

RELATIVE RESISTANCE (AFTER 1 MINUTE) OF ORDINARY GUTTAPERCHA AT DIFFERENT TEMPERATURES, FOR ALL CORES IN WHICH THE THICKNESS OF GUTTAPERCHA DOES NOT EXCEED 0·11 INCH.—*W. Smith.*

Temperature.		Relative Resistance.*	Log. Resistance.
Fah.	Cent.		
32	0·0	23·622	·373317
33	0·5	21·947	·341375
34	1·1	20·391	·309439
35	1·6	18·945	·277495
36	2·2	17·602	·245562
37	2·7	16·354	·213624
38	3·3	15·195	·181701
39	3·8	14·117	·149742
40	4·4	13·116	·117801
41	5·0	12·186	·085861
42	5·5	11·322	·053923
43	6·1	10·52	·022016
44	6·6	9·774	·990072
45	7·2	9·081	·958134
46	7·7	8·437	·926188
47	8·3	7·839	·894261
48	8·8	7·283	·862310
49	9·4	6·767	·830396

The above table is for new core, as guttapercha improves greatly with age.

* For example:—The resistance at 32° Fah. is 23·622 times greater than at 75° Fah. Therefore, in order to reduce the observed resistance at any temperature to what it will be at 75° Fah., refer to the above table, and divide the observed resistance by the number in the relative resistance column, found opposite the temperature of the G.P. at time of test.

RELATIVE RESISTANCE (AFTER 1 MINUTE) OF ORDINARY GUTTAPERCHA AT DIFFERENT TEMPERATURES, FOR ALL CORES IN WHICH THE THICKNESS OF GUTTAPERCHA DOES NOT EXCEED 0·11 INCH.—*Continued.*

Temperature.		Relative Resistance.	Log. Resistance.
Fah.	Cent.		
50	10·0	6·287	·798444
51	10·5	5·841	·766487
52	11·1	5·427	·734560
53	11·6	5·042	·702603
54	12·2	4·685	·670710
55	12·7	4·353	·638789
56	13·3	4·044	·606811
57	13·8	3·757	·574841
58	14·4	3·491	·542950
59	15·0	3·244	·511081
60	15·5	3·013	·478999
61	16·1	2·800	·447158
62	16·6	2·601	·415140
63	17·2	2·417	·383277
64	17·7	2·245	·351216
65	18·3	2·086	·319314
66	18·8	1·938	·287354
67	19·4	1·801	·255514
68	20·0	1·673	·223496
69	20·5	1·555	·191730
70	21·1	1·444	·159567
71	21·6	1·342	·127753
72	22·2	1·247	·095867
73	22·7	1·158	·063709
74	23·3	1·076	·031812
75	23·8	1·000	·000000

RELATIVE RESISTANCE (AFTER 1 MINUTE) OF ORDINARY GUTTAPERCHA AT DIFFERENT TEMPERATURES, FOR ALL CORES IN WHICH THE THICKNESS OF GUTTAPERCHA DOES NOT EXCEED 0·11 INCH.—*Continued.*

Temperature.		Relative Resistance.	Log. Resistance.
Fah.	Cent.		
76	24·4	·9418	·973959
77	25·0	·8870	·947924
78	25·5	·8354	·921895
79	26·1	·7867	·895809
80	26·6	·7410	·869818
81	27·2	·6978	·843731
82	27·7	·6572	·817698
83	28·3	·6190	·791691
84	28·8	·5829	·765594
85	29·4	·5490	·739572
86	30·0	·5171	·713575
87	30·5	·4870	·687529
88	31·1	·4586	·661434
89	31·6	·4319	·635383
90	32·2	·4068	·609381
91	32·7	·3831	·583312
92	33·3	·3608	·557267
93	33·8	·3398	·531223
94	34·4	·3200	·505150
95	35·0	·3014	·479143
96	35·5	·2839	·453165
97	36·1	·2674	·427161
98	36·6	·2518	·401056
99	37·2	·2371	·374932
100	37·7	·2233	·348889

Resistance and capacity.—A plate of guttapercha, 1 square foot surface, and 1 mil thick, has a *resistance* = 1,066 megohms at 75° Fah.; and its electro-static capacity = ·1356 microfarads.

The insulation resistance, in megohms, at 75° Fah., of an ordinary guttapercha cable or condenser, multiplied by its electro-static capacity, in microfarads = 144·4, after one minute's electrification.

Ratio of $\frac{D}{d}$ for strand and solid conductors.

A solid wire, covered with guttapercha—

$$\frac{D}{d} = \sqrt{1 + 8{\cdot}93\frac{W}{w}}$$

A strand, covered with guttapercha—

$$\frac{D}{d} = 1{\cdot}05\sqrt{1 + 6{\cdot}97\frac{W}{w}}$$

Where D = diameter of core, and d = diameter of wire or mean diameter of strand, both in mils; W = weight of guttapercha, and w = weight of conductor, both in lbs.

The **electro-static capacity** per nautical mile of any guttapercha core is approximately

$$\frac{0{\cdot}1877}{\log. D - \log. d} \text{ microfarads.}$$

The **electro-static capacity** of guttapercha core, as compared with india-rubber core of similar size, is as 120 to 100 nearly.

To find Resistance, after 1 Minute, and Capacity per Knot, of any Ordinary and of Willoughby Smith's Guttapercha Core, from the Relative Weights or Diameters of $\left(\frac{\text{Insulator}}{\text{Conductor}}\right)$.

$\frac{W}{w}$	$\frac{D}{d}$	Resistance per knot at 24° C. in megohms.		Electro-static capacity per knot in microfarad.	
		Ordinary.	Smith's.	Ordinary.	Smith's.
1·00	2·80	360	164	·4007	·3238
1·01	2·81	361	164	·3995	·3228
1·02	2·82	363	165	·3982	·3217
1·03	2·83	364	165	·3969	·3207
1·04	2·85	366	166	·3945	·3188
1·05	2·86	367	167	·3934	·3178
1·06	2·87	368	167	·3921	·3171
1·07	2·88	369	168	·3910	·3159
1·08	2·90	372	169	·3886	·3140
1·09	2·91	374	170	·3864	·3122
1·10	2·92	375	170	·3853	·3113
1·11	2·93	376	171	·3841	·3104
1·12	2·94	377	171	·3830	·3095
1·13	2·95	378	172	·3820	·3086
1·14	2·96	379	172	·3808	·3077
1·15	2·98	381	173	·3788	·3060
1·16	2·99	382	174	·3777	·3051
1·17	3·00	383	174	·3766	·3043
1·18	3·01	384	175	·3756	·3035
1·19	3·02	386	175	·3746	·3026
1·20	3·03	387	176	·3735	·3018
1·21	3·04	388	176	·3725	·3010
1·22	3·06	390	177	·3705	·2994
1·23	3·07	391	178	·3695	·2986
1·24	3·08	392	178	·3686	·2978
1·25	3·09	393	179	·3675	·2970

When the ratio between the weights, W, of percha and of copper, *w*, are given, the resistance and capacity of the core are the same, whatever be the absolute value of these weights. The same is true of the relative diameters, D and *d*. In using the above table, we have only to ascertain

To find Resistance, after 1 Minute, and Capacity per Knot, of any Ordinary and of Willoughby Smith's Guttapercha Core, from the Relative Weights or Diameters of $\left(\frac{\text{Insulator}}{\text{Conductor}}\right)$.

$\frac{W}{w}$	$\frac{D}{d}$	Resistance per knot at 24° C. in megohms.		Electro-static capacity per knot in microfarads.	
		Ordinary.	Smith's.	Ordinary.	Smith's.
1·26	3·10	395	179	·3657	·2962
1·27	3·11	396	180	·3647	·2947
1·28	3·12	397	181	·3638	·2939
1·29	3·13	398	181	·3628	·2932
1·30	3·14	399	182	·3619	·2924
1·31	3·15	400	182	·3611	·2917
1·32	3·17	402	183	·3593	·2902
1·33	3·18	403	183	·3583	·2895
1·34	3·19	404	184	·3579	·2888
1·35	3·20	405	184	·3569	·2881
1·36	3·21	406	185	·3559	·2874
1·37	3·22	407	185	·3544	·2867
1·38	3·23	408	186	·3538	·2860
1·39	3·24	409	186	·3531	·2853
1·40	3·25	410	186	·3521	·2846
1·41	3·26	411	187	·3512	·2839
1·42	3·27	412	187	·3502	·2833
1·43	3·28	413	188	·3493	·2826
1·44	3·29	414	188	·3484	·2819
1·45	3·30	415	189	·3476	·2806
1·46	3·31	416	189	·3467	·2800
1·47	3·32	418	190	·3459	·2793
1·48	3·33	419	190	·3450	·2787
1·49	3·34	420	191	·3441	·2781
1·50	3·35	421	191	·3433	·2774
1·51	3·36	422	192	·3425	·2768

The quotient $\frac{\text{weight of percha}}{\text{weight of copper}}$, or $\frac{\text{diameter of percha}}{\text{diameter of copper}}$, and the table, gives by inspection the resistance at 24° C. in megohms, and the electro-static capacity in microfarads.

Willoughby Smith's Improved Guttapercha.

The **specific gravity** of guttapercha prepared by Mr. Willoughby Smith's process is the same as that of ordinary guttapercha.

The **mechanical strength** of this material is about 12 per cent. greater than that of ordinary guttapercha.

The **electro-static capacity**, k, per knot of a core of Smith's guttapercha is approximately

$$k = \frac{0{\cdot}15163}{\log. \frac{D}{d}} \text{ microfarads.}$$

The **Insulation-resistance**, R, per knot of Smith's guttapercha core at 75° Fah., after one minute's electrification, is approximately

$$R = 350 \log. \frac{D}{d} \text{ megohms.}$$

The **resistance** after the first minute, of Smith's guttapercha at 32° Fah., is about the same as that of ordinary guttapercha. After a long application of the battery at this temperature the ratio falls to 72 : 100, about.

The **resistance** after the first minute, of Smith's guttapercha at 75° Fah., compared with that of ordinary guttapercha, is as 67 to 100, or about 30 per cent. inferior.

RELATIVE RESISTANCE (AFTER 1 MINUTE) OF WILLOUGHBY SMITH'S IMPROVED GUTTAPERCHA AT DIFFERENT TEMPERATURES, FOR ALL CORES IN WHICH THE THICKNESS OF GUTTAPERCHA DOES NOT EXCEED 0·110 INCH.—*W. Smith.*

Temperature.		Relative Resistance.*	Log. Resistance.
Fah.	Cent.		
32	0·0	27·913	·445807
33	0·5	25·834	·412192
34	1·1	23·91	·378580
35	1·6	22·128	·344942
36	2·2	20·48	·311330
37	2·7	18·954	·277701
38	3·3	17·542	·244079
39	3·8	16·235	·210452
40	4·4	15·025	·176815
41	5·0	13·906	·143202
42	5·5	12·87	·109579
43	6·1	11·911	·075948
44	6·6	11·024	·042339
45	7·2	10·203	·008728
46	7·7	9·442	·975064
47	8·3	8·739	·941462
48	8·8	8·088	·907841
49	9·4	7·485	·874192

* The above table is for new core, as this core, like ordinary guttapercha, improves greatly with age. See footnote, p. 261.

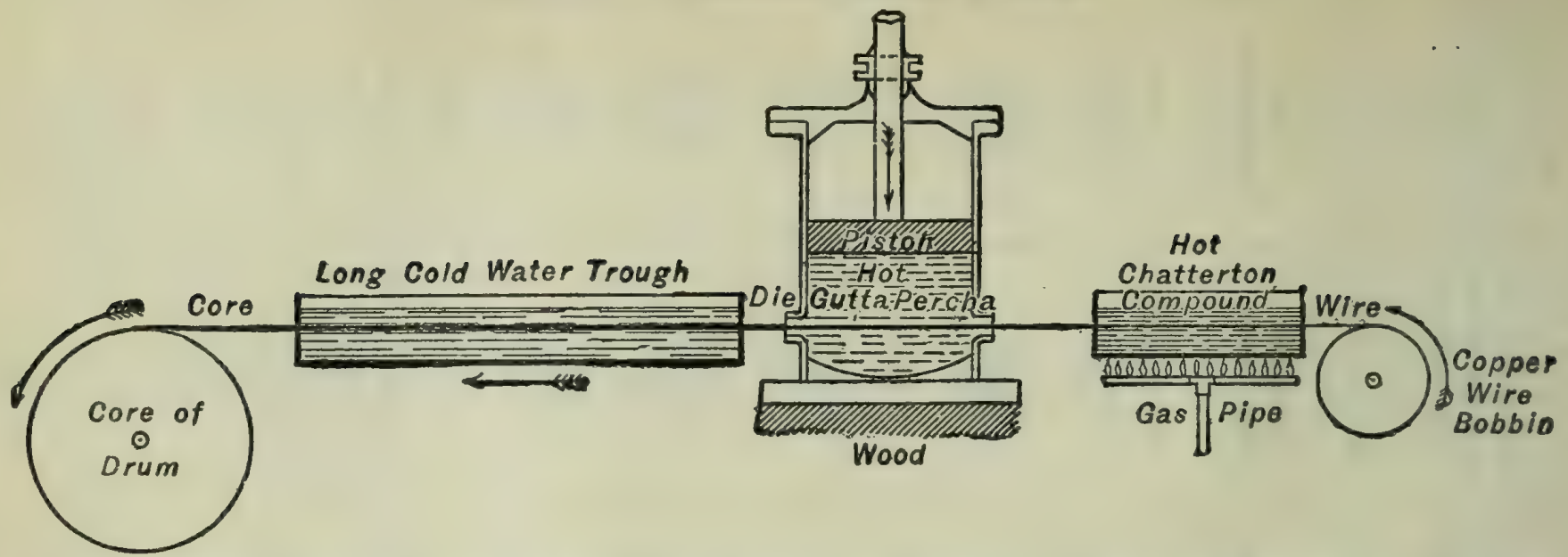
RELATIVE RESISTANCE (AFTER 1 MINUTE) OF WILLOUGHBY SMITH'S IMPROVED GUTTAPERCHA AT DIFFERENT TEMPERATURES, FOR ALL CORES IN WHICH THE THICKNESS OF GUTTAPERCHA DOES NOT EXCEED 0·110 INCH.—*W. Smith.*

Temperature.		Relative Resistance.	Log. Resistance.
Fah.	Cent.		
50	10·0	6·928	·840608
51	10·5	6·412	·806994
52	11·1	5·934	·773348
53	11·6	5·492	·739731
54	12·2	5·083	·706120
55	12·7	4·704	·672467
56	13·3	4·354	·638888
57	13·8	4·029	·605197
58	14·4	3·729	·571592
59	15·0	3·451	·537945
60	15·5	3·194	·504335
61	16·1	2·956	·470704
62	16·6	2·736	·437116
63	17·2	2·532	·403464
64	17·7	2·343	·369772
65	18·3	2·169	·336260
66	18·8	2·007	·302547
67	19·4	1·858	·269046
68	20·0	1·719	·235276
69	20·5	1·591	·201670
70	21·1	1·473	·168203
71	21·6	1·363	·134496
72	22·2	1·261	·100715
73	22·7	1·167	·067071
74	23·3	1·080	·033424
75	23·8	1·000	·000000

RELATIVE RESISTANCE (AFTER 1 MINUTE) OF WILLOUGHBY SMITH'S IMPROVED GUTTAPERCHA AT DIFFERENT TEMPERATURES, FOR ALL CORES IN WHICH THE THICKNESS OF GUTTAPERCHA DOES NOT EXCEED 0·110 INCH.—*W. Smith.*

Temperature.		Relative Resistance.	Log. Resistance.
Fah.	Cent.		
76	24·4	·9375	·971971
77	25·0	·8789	·943940
78	25·5	·8240	·915927
79	26·1	·7725	·887899
80	26·6	·7242	·859859
81	27·2	·6789	·831806
82	27·7	·6365	·803798
83	28·3	·5967	·775756
84	28·8	·5594	·747723
85	29·4	·5245	·719746
86	30·0	·4917	·691700
87	30·5	·4609	·663607
88	31·1	·4321	·635584
89	31·6	·4051	·607562
90	32·2	·3798	·579555
91	32·7	·3561	·551572
92	33·3	·3338	·523486
93	33·8	·3130	·495544
94	34·4	·2934	·467460
95	35·0	·2751	·439491
96	35·5	·2579	·411451
97	36·1	·2417	·383277
98	36·6	·2266	·355260
99	37·2	·2125	·327359
100	37·7	·1992	·299289

MAKING GUTTAPERCHA CORE.



STANDARD TEMPERATURE FOR DIELECTRIC TESTS.—It is usual in specifications for good cable-core to specify that the conductor and dielectric shall have a certain resistance at 75° Fah., and all tests taken at other temperatures are reduced by tables to that temperature for comparison. It is also usual to specify that the core shall be kept for 24 hours at a constant temperature of 75° Fah. before being tested and passed for sheathing; but it is evident that tests taken at this temperature are not nearly so searching for small faults (owing to the absolute resistance being low) as they would be if taken at a lower temperature, say from 40° to 50°. Some well-known firms, therefore, make a point of taking final tests before passing core for sheathing, at as low a temperature as practicable.

Guttapercha Covered Wires for Land Line, Telegraph, and Telephone Work. (*T. Fletcher*).

The following table has been calculated from the data :—

D = outside diameter of dielectric in mils.
d = diameter of conductor in mils.
l = length ,, in feet.
w = weight ,, in grains.

Specific gravity of pure copper is calculated from the resistance of foot-grain and foot-mil., determined by Dr. Matthiessen = 8·9263.

Weight of one cubic foot pure copper = 556·3 lbs. Weight of any wire in grains = $d^2\ l \times$ specific gravity × ·002379363.

Resistance of one foot-mil. pure copper at 32° F. = 9·718 ohms.

Resistance of one foot-grain pure copper at 32 F. = ·2064 ohms.

To correct any pure copper resistance from 32° F. to 75° F. multiply by 1·09546.

* Insulation resistance of any guttapercha wire per statute mile, at 75° F. = 920 log. $\frac{D}{d}$ megohms.

* Weight of guttapercha per statute mile varies from

$$\frac{D^2 - d^2}{560} \text{ to } \frac{D^2 - d^2}{580}$$

Inductive capacity of any guttapercha wire

$$= \frac{144{\cdot}4}{\text{Insulation resistance in megohms after 1 minute at 75° F.}} \text{ microfarads.}$$

* Based on actual measurement of a large number of samples supplied by the best manufacturers.

INSULATION RESISTANCE AND INDUCTIVE CAPACITY OF G.-P. COVERED WIRE AFTER ONE MINUTE OF ELECTRIFICATION AT 75° F.—*Fletcher*.

$\frac{D}{d}$	Res. per Mile. Megohms.	Inductive Capacity per Mile. Micro-farads.	$\frac{D}{d}$	Res. per Mile. Megohms.	Inductive Capacity per Mile. Micro-farads.	$\frac{D}{d}$	Res. per Mile. Megohms.	Inductive Capacity per Mile. Micro-farads.	$\frac{D}{d}$	Res. per Mile. Megohms.	Inductive Capacity per Mile. Micro-farads.
2·50	366·1	·3945	2·74	402·7	·3585	2·98	436·3	·3310	3·22	467·2	·3091
2·52	369·3	·3910	2·76	405·6	·3560	3·00	439·0	·3290	3·24	469·7	·3074
2·54	372·4	·3877	2·78	408·5	·3535	3·02	441·6	·3270	3·26	472·2	·3058
2·56	375·6	·3845	2·80	411·4	·3510	3·04	444·3	·3250	3·28	474·6	·3042
2·58	378·7	·3813	2·82	414·2	·3486	3·06	446·9	·3231	3·30	477·0	·3027
2·60	381·8	·3782	2·84	417·1	·3462	3·08	449·5	·3213	3·32	479·4	·3012
2·62	384·8	·3752	2·86	419·9	·3439	3·10	452·1	·3194	3·34	481·8	·2997
2·64	387·9	·3723	2·88	422·6	·3417	3·12	454·6	·3176	3·36	484·2	·2982
2·66	390·9	·3694	2·90	425·4	·3394	3·14	457·2	·3158	3·38	486·6	·2967
2·68	393·9	·3666	2·92	428·2	·3372	3·16	459·7	·3141	3·40	489·0	·2953
2·70	396·9	·3639	2·94	430·9	·3351	3·18	462·2	·3124	3·42	491·3	·2939
2·72	399·8	·3612	2·96	433·6	·3330	3·20	464·7	·3107	3·44	493·6	·2925

INSULATION RESISTANCE AND INDUCTIVE CAPACITY OF G.-P. COVERED WIRE AFTER ONE MINUTE OF ELECTRIFICATION AT 75° F.—*Fletcher—Continued.*

$\frac{D}{d}$	Res. per Mile. Megohms.	Inductive Capacity per Mile. Micro-farads.	$\frac{D}{d}$	Res. per Mile. Megohms.	Inductive Capacity per Mile. Micro-farads.	$\frac{D}{d}$	Res. per Mile. Megohms.	Inductive Capacity per Mile. Micro-farads.	$\frac{D}{d}$	Res. per. Mile. Megohms.	Inductive Capacity per Mile. Micro-farads.
3·46	496·0	·2912	3·72	524·9	·2751	3·98	551·9	·2616	4·24	577·2	·2502
3·48	498·3	·2898	3·74	527·0	·2740	4·00	553·9	·2607	4·26	579·1	·2494
3·50	500·6	·2885	3·76	529·2	·2729	4·02	555·9	·2598	4·28	580·9	·2486
3·52	502·8	·2872	3·78	531·3	·2718	4·04	557·9	·2588	4·30	582·8	·2478
3·54	505·1	·2859	3·80	533·4	·2707	4·06	559·8	·2579	4·32	584·6	·2470
3·56	507·3	·2846	3·82	535·5	·2697	4·08	561·8	·2570	4·34	586·5	·2462
3·58	509·6	·2834	3·84	537·6	·2686	4·10	563·8	·2561	4·36	588·3	·2454
3·60	511·8	·2821	3·86	539·7	·2676	4·12	565·7	·2553	4·38	590·2	·2447
3·62	514·0	·2809	3·88	541·7	·2666	4·14	567·6	·2544	4·40	592·0	·2439
3·64	516·2	·2797	3·90	543·8	·2656	4·16	569·6	·2535	4·42	593·8	·2432
3·66	518·4	·2785	3·92	545·8	·2645	4·18	571·5	·2527	4·44	595·6	·2424
3·68	520·6	·2774	3·94	547·9	·2636	4·20	573·4	·2518	4·46	597·4	·2417
3·70	522·7	·2762	3·96	549·9	·2626	4·22	575·3	·2510	4·48	599·2	·2410

SUBMARINE CABLES.

SPECIFICATION FOR PLATINO-BRAZILEIRA CABLE, made and laid by Messrs. SIEMENS BROTHERS, Charlton, between Rio de Janeiro and Chuy, South America. Sir WILLIAM THOMSON and Prof. FLEEMING JENKIN, Consulting Engineers.

Core.—The core to consist of **7** wires copper strand, covered with guttapercha. The following are to be the weights of the core:—

Copper.—**7** wires laid into a strand, weighing **107** lbs. per knot.

Guttapercha.—**3** coatings of guttapercha and Chatterton's compound = **150** lbs. per knot.

Main Cable A.—This cable to consist of the following parts:—(**1.**) Core as above. (**2.**) A good and sufficient serving of jute yarn, wet and saturated with brine. (**3.**) Outer covering to consist of **11** galvanised iron wires, of the quality specified below, and the diameter of each wire to be **0·143** inch, or within **2·5** per cent. thereof; the whole to receive **3** coatings of Clark's compound and **2** layers of jute yarn between; the whole weight of iron to be not less than **3,600** lbs. per knot.

Main Cable B.—The core, served as far as Cable A, to be covered with **10** iron galvanised wires of quality as specified below, the diameter of each wire to be **0·18**, or within **2·5** per cent. thereof; the whole to receive **3** coatings of Clark's compound, with **2** layers of jute yarn between the coatings, in alternate layers, the total weight to be not less than **5,160** lbs. per knot.

Shore End C.—The Conductor and Insulator to be the same as for Cable A, with a sufficient

serving of the same materials, covered with **12** galvanised iron wires, **0·238** inch diameter, of the quality specified below, the total weight of iron per knot to be not less than **96** cwts.; the whole to receive **3** coatings of Clark's compound, with two layers of jute yarn between the coatings, in alternate lay.

Shore Cable D.—This Shore End Cable shall consist of Cable A, without the outer servings of jute and Clark's compound, but further served with a well-tarred jute yarn, and sheathed with **12** strands of **3** wires each, of the quality specified below; the total weight of these wires per knot to be not less than **275** cwts.—that is to say, of not less than **12** strand of **3** wires, **0·230** inch diameter. Each intermediate cable to be finished off with suitable tapers.

I. **Quality of Materials.**—The iron wire supplied for all the cables shall be of the quality known as **best best** annealed galvanised, and of a quality superior to the ordinary best best, and shall be submitted to such tests for strength and brittleness as may be agreed upon between the engineers and contractors. See Index for tests of wire.

A margin of **2·5** per cent. above and below contract weight will be allowed, provided the average weight be adhered to. No wire of brittle quality shall be put into the cables, and the engineers, or their assistants, shall have power to reject any hanks which break frequently in the closing machine, or any of unsatisfactory quality. No weld shall be made in any wire within **12** feet of any other weld of the same, or any other wire of the cable, except in the strands of shore end D.

Weight of bundle in lbs.	Diameter of Wire.	No. of twists in 6 in.	Bending and Unbending round a Spindle.
162	0·143 in.*	13	0·572 inch.
...	0·180 ,,	10	0·720 ,,
280	0·230 ,,	5	0·920 ,,
289	0·238 ,,	6	0·952 ,,

II. Cables A, B, C are to be covered, after the wires are laid on, with **3** coatings of mineral pitch and silica, in the proportions of **60** and **40** parts respectively, and with **2** servings of tarred jute yarn laid alternately, the first coating of the compound being (laid) next the wire, then a serving of jute yarn, the compound, then the jute yarn, and lastly, compound. The compound to be applied hot, and the yarn to be laid on immediately after its application. Such special precautions to be taken against injury to the core, in case of the machinery stopping, as the Company's engineers shall direct. The yarn is to be everywhere covered with compound, and the outside smooth and regular.

The Telegraph Construction and Maintenance Company generally apply an outer serving of two of Johnson and Phillips's patent tapes, laid on spirally in opposite directions, and three coatings of Clark's compound, the first coating being cool and laid on next the wires.

III. The **Conductors** to consist of a strand of **7** wires of annealed copper of the best quality

* 0·143-inch wire was brazed by scarfing the joints and hard soldering them. All other sizes were welded, but they could not be well done, owing to the deteriorating action which the galvanising had upon the iron—*i.e.*, they could not be welded so as to bind into a semi-circle and back again, but it was found that the brazing, if carefully effected, and with a good pressure and flow of gas and wind combined, made the better joint.

and manufacture. The interstices in the strand to be completely filled with insulating compound. The mean resistance of the strand, weighing **107** lbs. per knot, to be not more than **12·15** ohms at **75°** Fah. No single knot of conductor to have a resistance exceeding the numbers given above by **2·5** per cent.

IV. The **Insulation** resistance of guttapercha core shall not be less, when tested at **75°** Fah., than **300** megohms, **14** days after manufacture and after **2** minutes' electrification. If the resistance of any portion of the guttapercha at **75°** Fah., at any period of the manufacture, fall below the above specified limit, the cable is to be **rejected.**

V. The **Joints** in the core are to be made by experienced workmen, and no joint at the cable works is, under any circumstances, to be made, except in the presence of one of the Company's inspectors, who will test and pass each joint separately from the rest of the cable. The contractors shall allow time for a thoroughly satisfactory test, **6 hours** after the joints have been made and kept immersed in water.

VI. The **Serving** shall consist of yarn applied wet and **saturated** with brine.

VII. The **Core** shall be delivered in lengths of not less than **1 mile**—it shall be immersed in water, of a temperature of **75°** Fah., for at least **24** hours before the tests are made. The length of coil shall be given to the Company's engineers. A margin of **2·5** per cent. over the specified weight shall be allowed, but the mean weight of the core for the whole cable must at least equal that of the specified weight. All coils approved of by the Company's engineers shall be re-delivered for further manufacture, and all coils

rejected by the engineers shall be retained at the works for inspection till the close of the manufacture. All coils shall be numbered, labelled, and registered, and the engineers shall be kept cognisant of the position and portion of the cable into which each length of core is inserted.

VIII. The core shall be coiled on drums, and shall be carefully kept until serving is begun, the drums to be carefully protected by iron covers during the transit from the insulating to the sheathing factories—the served core to be kept in tanks under water, the water to be withdrawn from the tanks and replaced by fresh, so often as required by the engineers. The tanks are to be roofed over. Correct indicators are to be attached to the closing machines, showing the exact amount of cable manufactured, and the completed cable is to be marked at every 100 miles in the usual manner, and kept under water as far as possible, both in the factory and on board ship, until submerged, &c., &c.

Teredoes.—In order to prevent the core of submarine cables becoming pierced and damaged by teredoes or other marine borers, the Telegraph Construction and Maintenance Company cover, where thought advisable, the guttapercha of their core with—1st, a serving of strong white canvas tape; 2nd, Muntz metal (or brass taping); 3rd, canvas tape steeped in stearine. The last tape coating prevents galvanic action between the brass taping and the iron sheathing. This has been proved practically in the Eastern Extension and Eastern and South African Companies' cables to be a perfect remedy. Teredoes do not attack india-rubber or Hopper's core injuriously.

SUBMARINE CABLES* (RECENTLY LAID.)

ABSTRACT FORM, SHOWING GENERAL CONDITION OF CABLE DURING 30 DAYS' TESTS.—*By Clark, Forde, and Taylor.*

1. Length of cable,	From Cable house to Cable house,	knots	1900
2. Distance over water,		,,	1795·24
3. Percentage of slack,		%	6·3
4. Depth of water,	Maximum sounding taken,	Fms.	1296
	Mean (about),	,,	488
5. Pressure at bottom per square inch,	Maximum,	lbs.	3460
	Mean,	,,	1265
6. Mean copper resistance tested at 75° Fah. per knot (approx.),		ohms.	4·936
7. Do. after laying,	Total observed,	,,	8809
	Do. corrected,	,,	8824
	Per knot do.,	,,	4·644
8. Mean temperature of cable calculated from C. R.,		Fah.	45·7°
9. Dielectric resistance, (Mean of both currents, from several days' tests)	Total: 1st min. calculated	Megs	2·72
	Total: 1st ,, observed	,,	2·46
	Total: 5th ,, ,,	,,	3·58
	Total: 10th ,, ,,	,,	3·90
	Total: 30th ,, ,,	,,	4·71
	Per knot: 1st min. calculated	,,	5168
	Per knot: 1st ,, observed	,,	4674
	Per knot: 5th ,, ,,	,,	6802
	Per knot: 10th ,, ,,	,,	7410
	Per knot: 30th ,, ,,	,,	8947
10. Electro-static capacity,	Total,	Mfds.	604
	Per knot.	,,	0 318
11. Dielectric resistance per knot at 75° Fah. on first manufacture, 1st minute,		Megs	296†
12. Dielectric resistance per knot reduced to 75° Fahrenheit, 1st minute,	After shipment, tested at mean temp. 51° Fah.,	,,	467
	On arrival out, tested at mean temp. 71° Fah.,	,,	476
	After submersion mean temp. 45·7° Fah.,	,,	490†

* For details of tests taken of this cable, see Rankine's "Rules and Tables," pp. 341 to 343, sixth edition.

† Improvement in dielectric resistance from time of manufacture to after submersion, 65·5 per cent.

Tests of Atlantic Cables, &c.,*

Made and Laid by Messrs. Siemens Brothers & Co.

Cable.	When laid.	Total length, knots.	Copper Resistance in Siemens' Units.		
			Total.	Per knot.	Mean from Factory Tests per knot at 75° Fah.
Direct United States, ...	1875	2422·56	7312	3·018	...
American Telegraph and Cable Co., .	1881	2517·76	8014	3·184	3·466
Do. do. do., . . .	1882	2562·70	8264	3·225	3·509
	Aug.		Ohms.	Ohms.	Ohms.
Djeddah to Suakin (Red Sea). Mean Temp. of Cable, 66° Fah., . . .	1882	187·66	2115	11·27	11·49

* From Rankine's "Rules and Tables." Sixth Edition.

Tests of Atlantic Cables, &c.—*Continued.*

Electro-static Capacity in Microfarads.			Insulation Resistance, in Million Siemens' Units.			Tests taken by, and Date.
Total.	Per Knot.	Mean from Factory Tests per knot at 75° Fah.	Total, 1st min.	Per knot, 1st min.	Mean from Factory Tests per knot at 75° Fah., 1st min.	
987·6	·4077	...	2·26	5,475	...	Fife Jamieson, 9/2/76.
887	·352	·3720	7·85	19,770	510	Frank Jacob, 1/7/82.
925	·361	·3657	7·4	18,970	508	Do., do.
			Per Knot in Megohms.			
			1st min.	10th min.	1st min.	
56·18	·2994	·2984	9,382	18,760	2140	Frank Jacob, 21/10/82.

Electrical Data of Submarine Cables.*

Manufactured and laid by The Telegraph Construction and Maintenance Company, Limited.

Cable. (For Mechanical data, see pp. 287, 288.)	Date.	Length laid, knots.	Electrical Values at 24° Cent. in B.A. Units.			
			Conductor.		Dielectric (G.P.)	
			Resistance per knot, ohms.	Specific conductivity, pure copper = 100.	Resistance per knot, megohms.	Electro-static capacity per knot, Microfarads.
Placentia and St. Pierre, . .	1872	110	11·930	93·4	378	·303
St. Pierre and Sydney, . .	,,	182				
Constantinople, ...	,,	5	...	...	...	...
England and Spain, . . .	1873	619	10·528	94·4	321	·296
Vigo and Lisbon, . . .	,,	247				
Ireland and Newfoundland, .	,,	1876	3·167	94·1	254	·353
Placentia and Sydney, . .	,,	314	12·070	92·3	451	·317
Sydney and Placentia, . .	,,	280				
Neuwerk and Heligoland, .	,,	31	11·879	93·8	262	·312
Lisbon and Madeira, . . .	,,	613	10·567	94·0	296	·297
Alexandria and Crete, . .	,,	359	11·780	94 6	335	·307

* From "Rankine's Rules and Tables," sixth edition.
† For cables prior to 1872, see "Electrical Tables," Clark and Sabine.

Electrical Data of Submarine Cables.—*Continued.*

Cable. (For Mechanical data, see. pp. 289-291.)	Date.	Length laid, knots.	Electrical Values at 24° Cent. in B.A. Units. Conductor. Resistance per knot, ohms.	Conductor. Specific conductivity, pure copper = 100.	Dielectric (G.P.) Resistance per knot, megohms.	Dielectric (G.P.) Electro-static capacity per knot, Microfarads.
Crete and Zante,	1873	238	11·668	95·5	258	·309
Zante and Otranto,	1874	187	11·553	96·4	256	·305
Italy and Sicily,	"	5	...	...	...	...
Jamaica and Porto Rico,	"	647 }	11·535	96·7	274	·306
Martinique and Dominica,	"	37 }				
Madeira and St. Vincent,	"	1196	10·436	95·2	285	·297
Kilia and Odessa,	"	349	11·722	95·1	278	·303
St. Vincent and Pernambuco,	"	1844	4·836	96·7	312	·302
Ireland and Newfoundland,	"	1837	3·135	95·1	282	·332
Holland,	"	3	...	...	...	...
Italy and Sardinia,	1875	118	12·024	92·7	373	·296
Yankalilla and Kingscote,	"	38	11·641	95·8	228	·300
Australia and New Zealand,	1876	1282	11·708	95·2	273	·300
Cook's Straits, N.Z.,	"	45	11·851	94·0	417	·307
Suez and Aden,	"	1443	10·180	97·6	333	·301
Aden and Bombay,	1877	1888	6·800	97·4	344	·314

Electrical Data of Submarine Cables—*Continued.*

Cable. (For Mechanical data, see pp. 291, 293.)	Date.	Length laid, knots.	Electrical Values at 24° Cent. in B.A. Units. Conductor. Resistance per knot, ohms.	Conductor. Specific conductivity, pure copper = 100.	Dielectric (G.P.) Resistance per knot, megohms.	Dielectric (G.P.) Electro-static capacity per knot, Microfarads.
Penang and Rangoon,	1877	853	11·561	96·4	341	·308
Marseilles and Bona,	"	463	11·738	94·9	590	·315
Bona and Malta,	"	382	11·644	95·7	618	·302
Para and Maranham,	1878	309	11·739	94·9	493	·301
Torpedo Cables,	"	289	12·609	96·5	339	·309
Alexandria and Cyprus	"	327	11·740	94·9	382	·281
Penang and Malacca,	1879	274	11·610	96·0	442	·282
Natal and Delagoa Bay,	"	344	11·586	96·2	461	·282
Delagoa and Mozambique,	"	966	11·693	95·3	438	·284
Malacca and Singapore,	"	116	11·643	96·0	425	·286
Germany and Norway, 3 Conductors,	"	251	1,12·499	95·4	357	·285
			2,12·477	95·6	342	·286
			3,12·487	95·5	351	·285
Mozambique and Zanzibar,	"	631	11·634	95·8	391	·282
Singapore and Java,	"	919	11·576	96·3	378	·282
Aden and Zanzibar,	"	1908	4·935	96·7	296	·314

Electrical Data of Submarine Cables.—*Continued.*

Cable. (For Mechanical data, see pp. 294, 295)	Date.	Length laid, knots.	Electrical Values at 24° Cent. in B.A. Units.			
			Conductor.		Dielectric (G.P.)	
			Resistance per knot, ohms.	Specific conductivity, pure copper = 100.	Resistance per knot, megohms.	Electro-static capacity per knot, Microfarads.
Java and Australia, . . .	1880	1131	11·644	95·7	345	·282
Wanganui and Wakapuaka, .	"	108	11·378	97·9	409	·281
Hong Kong and Luzon, . .	"	528	11·453	97·3	456	·280
Placentia and St. Pierre, 3 Conductors, ...	"	109	1,11·442	97·4	517	·282
			2,11·414	97·6	494	·282
			3,11·446	97·4	502	·282
Ireland and Newfoundland, .	"	1423	4·161	95·5	478	315
England and Norway, . .	"	423	6·864	96·5	500	·303
Norway and Sweden, . .	"	94	6·733	98·4	440	·303
St. Pierre and Sydney, 3 Conductors, ...	"	185	1,11·414	97·6	651	·282
			2,11·387	97·9	600	·282
			3,11·422	97·6	613	·282
Singapore and Batavia, . .	1881	537	11·297	98·7	709	·316
Trieste and Corfu, . . .	"	550	9·155	100·0	658	·352
Valentia and Greitseil, . .	1882	841	9·098	100·0	567	·354

Mechanical Data of Submarine Cables.*

Manufactured and Laid by the Telegraph Construction and Maintenance Co., Limited.†

For Electrical Data, see pp. 283-286.

Cables.	Date.	Length Laid. Knots.	Weight per Knot. Copper.	Insulator, G. P.	Iron.	Jute.	Asphalt, &c.	Complete.	Remarks.
			lbs.	lbs.	Tons.	Tons.	Tons.	Tons.	
Placentia and St. Pierre,	1872	110	107	140	2·344	·153	...	2·607	Main.
			,,	,,	9 845	·519	1·145	11·619	Shoreends.
St. Pierre and Sydney, . .	,,	182	,,	,,	2·344	·153	...	2·607	Main.
			,,	,,	9·845	·519	1·145	11·619	Shoreends.
Constantinople,	,,	5	,,	,,	1·193	·107	·393	1·803	
England and Spain, . . .	1873	619	120	175	9·845	·519	1·505	12·000	Shore.
			,,	,,	5·369	·350	·750	6 600	Intermed.
			,,	,,	2·687	·093	·475	3·382	,,
			,,	,,	1·900	·187	·412	2·630	,,
			,,	,,	·645	·095	·826	1·697	Main.
Vigo and Lisbon,	,,	247	120	175	9·845	·519	1·505	12·000	Shore.
			,,	,,	2·687	·093	·475	3·382	Main.
			,,	,,	5·369	·350	·750	6·600	Intermed.

* From Rankine's "Rules and Tables," sixth edition.

† For Cables prior to 1872, see "Electrical Tables," Clark and Sabine, pp. 256-259.

Mechanical Data of Submarine Cables—*Continued.*

Cables.	Date.	Length Laid	Weight per Knot.						Remarks.
		Knots.	Copper.	Insulator, G. P.	Iron.	Jute.	Asphalt, &c.	Complete.	
			lbs.	lbs.	Tons.	Tons.	Tons.	Tons.	
Ireland and Newfoundland, . . .	1873	1876	400	400	17·460	1·684	...	19·50	Shore.
			"	"	9·641	·641	1·989	12·628	Intermed.
			"	"	3·350	·164	·498	4·369	"
			"	"	2·419	·090	·588	3·454	"
			"	"	·662	·147	1·080	2·246	Main.
Placentia and Sydney, . .	"	314	107	140	17·460	1·684	...	19·254	Shore.
			"	"	9·641	·641	1·989	12·381	Intermed.
			"	"	3·350	·164	·498	4·122	Main.
Sydney and Placentia, .	"	280	"	"	17·460	1·684	...	19·254	Shore.
			"	"	9·0641	·641	1·989	12·081	Intermed.
			"	"	3·350	·164	·498	4·122	Main.
Neuwerk and Heligoland,	"	31	107	140	9·514	·666	1·371	11·661	Shore.
			"	"	5·917	·325	·691	7·043	Main.
Lisbon and Madeira, . .	"	613	120	175	9·450	·750	1·337	11·668	Shore.
			"	"	2·687	·094	·470	3·382	Intermed.
			"	"	1·900	·187	·412	2·630	"
			"	"	·636	·137	·940	1·845	Main.
Alexandria and Crete, . . .	"	359	107	140	9·845	·519	1·145	11·619	Shore.
			"	"	5·917	·325	·691	7·043	Intermed.
			"	"	1·038	·075	·337	1·56	Main.

Mechanical Data of Submarine Cables—*Continued.*

Cables.	Date.	Length Laid. Knots.	Weight per Knot. Copper.	Insulator, G. P.	Iron.	Jute.	Asphalt, &c.	Complete.	Remarks.
			lbs.	lbs.	Tons.	Tons.	Tons.	Tons.	
Crete and Zante,	1873	238	107	140	9·845	·5199	1·504	11·978	Shore.
			"	"	5·369	·350	·750	6·579	Intermed.
			"	"	1·918	·118	·573	2·719	"
			"	"	1·065	·055	·348	1·578	Main.
Zante and Otranto, . .	1874	187	107	140	9·845	·519	1·504	11·978	Shore.
			"	"	5·369	·350	·750	6·579	Intermed.
			"	"	1·065	·055	·348	1·578	Main.
Italy and Sicily,	"	5	107	140	9·495	·605	1·262	11·472	
Jamaica and Porto Rico,	"	647	107	140	9 495	·605	1·262	11·472	Shore.
			"	"	3·185	·129	·406	3·830	Intermed.
			"	"	1·145	·095	·297	1·647	Main.
Martinique and Dominica,	"	37	107	140	9·495	·605	1 262	11·472	Shore.
			"	"	3·185	·129	·406	3·830	Intermed.
			"	"	1·145	·095	·297	1·647	Main.
Madeira and St. Vincent,	"	1196	120	175	9·450	·750	1·337	11·668	Shore.
			"	"	2·687	·094	·470	3·382	Intermed.
			"	"	1 900	·187	·412	2·630	"
			"	"	·636	·137	·940	1·845	Main.
Kilia and Odessa,	"	349	107	140	5·325	·400	1·051	6·886	Shore.
			"	"	2·725	·275	·793	3·903	Intermed.
			"	"	1·038	·075	·337	1·500	Main.

Mechanical Data of Submarine Cables—*Continued.*

Cables.	Date.	Length Laid.	Weight per Knot.						Remarks.
		Knots.	Copper.	Insulator, G. P.	Iron.	Jute.	Asphalt, &c.	Complete.	
			lbs.	lbs.	Tons.	Tons.	Tons.	Tons.	
St. Vincent and Pernambuco, . . .	1874	1844	255	340	9·450	·762	1·337	11·816	Shore.
			"	"	1·900	·187	·412	2·766	Intermed.
			"	"	1·262	·063	·387	1·979	"
			"	"	·705	·153	1·084	2·209	Main.
Ireland and Newfoundland, . . .	"	1837	400	400	17·460	1·684	...	19·500	Shore.
			"	"	3·350	·164	·498	4·122	Intermed.
			"	"	·662	·147	1·080	2·246	Main.
Holland, . . .	"	3	107	140	2·278	·203	·387	2·978	
Italy and Sardinia, . . .	1875	118	107	140	1·145	·095	·297	1·647	Main.
Yankalilla and Kingscote,	"	38	107	140	9·845	·650	1·120	11·725	Shore.
			"	"	5·325	·400	1·051	6·880	Intermed.
			"	"	2·700	·095	·635	3·545	Main.
Australia and New Zealand, . . .	1876	1282	107	140	9·845	·650	1·120	11·720	Shore.
			"	"	2·700	·095	·635	3·54	Intermed.
			"	"	1·060	·080	·450	1·700	"
			"	"	·635	·200	·380	1·325	Main.
Cook's Straits, N.Z., . . .	"	45	107	166	7·623	·514	1·136	9·618	3 cores.
			107	140	8·412	·587	·635	9·741	Shore.
			"	"	4·075	·287	·400	4·872	Main.

Mechanical Data of Submarine Cables—*Continued.*

Cables.	Date.	Length Laid.	Weight per Knot.						Remarks.
		Knots.	Copper.	Insulator, G. P.	Iron.	Jute.	Asphalt, &c.	Complete.	
			lbs.	lbs.	Tons.	Tons.	Tons.	Tons.	
Suez and Aden,	1876	1443	120	175	9·951	·838	1·236	12·156	Shore.
			"	"	2·848	·101	·435	3·515	Intermed.
			"	"	1·867	·116	·392	2·506	"
			"	"	1·156	·101	·376	1·764	Main.
Aden and Bombay, .	1877	1888	180	240	11·399	·694	·571	12·850	Shore.
			"	"	9·813	·414	1·552	11·960	"
			"	"	5·389	·281	·687	6·544	Intermed.
			"	"	2·827	·111	·576	3·702	"
			"	"	·626	·201	·254	1·268	Main.
Penang and Rangoon, . .	"	853	107	140	9·800	·450	1·650	12·010	Shore.
			"	"	2·850	·125	·484	3·569	Intermed.
			"	"	1·060	·093	·291	1·554	Main.
Marseilles and Bona, . . .	"	463	107	140	9·800	·650	1·120	11·680	Shore.
			"	"	2·900	·244	·440	3·692	Intermed.
			"	"	1·062	·144	·297	1·613	Main.
Bona and Malta,	"	382	107	140	9·800	·650	1·120	11·680	Shore.
			"	"	5·337	·550	·475	6·472	Intermed.
			"	"	2·900	·244	·440	3·692	"
			"	"	1·062	·144	·297	1·613	Main.

Mechanical Data of Submarine Cables—*Continued.*

Cables.	Date.	Length Laid. Knots.	Weight per Knot. Copper.	Insulator, G. P.	Iron.	Jute.	Asphalt, &c.	Complete.	Remarks.
			lbs.	lbs.	Tons.	Tons.	Tons.	Tons.	
Para and Maranham, . .	1878	309	107	140	8·412	·587	·635	9·741	Shore.
			,,	,,	4·075	·287	·400	4·872	Intermed.
			,,	,,	2·900	·125	·237	3·372	Main.
Torpedo Cables,	,,	289	98	116	·718	·064	·447	1·324	4 cores.
			,,	,,	1·117	·150	·682	2·340	
			,,	,,	·856	·056	·285	1·292	
Alexandria and Cyprus, . .	,,	327	107	140	9·800	·650	1·120	11·680	Shore.
			,,	,,	2·900	·244	·440	3·692	Intermed.
			,,	,,	1·062	·144	·297	1·613	Main.
Penang and Malacca, . .	1879	274	107	140	10·350	·675	1·026	12·161	Shore.
			,,	,,	2·803	·225	·554	3·692	Main.
Natal and Delagoa, . . .	,,	344	107	140	13·647	·575	..	15·652	Shore.
			,,	,,	10·350	·675	1 026	12·161	,,
			,,	,,	5·230	·400	·781	6·521	Intermed.
			,,	,,	2·803	·225	·554	3·692	Main.
			,,	,,	·850	·050	·362	1·372	,,
Delagoa and Mozambique,	,,	966	107	140	10·350	·675	1·026	12·161	Shore.
			,,	,,	5·230	·400	·781	6·521	Intermed.
			,,	,,	2·803	·225	·557	3·692	,,
			,,	,,	·862	·075	·337	1·387	Main.
			,,	,,	·850	·050	·362	1·372	,,
			,,	,,	·625	·187	·517	1·442	,,

Mechanical Data of Submarine Cables—*Continued.*

Cables.	Date.	Length Laid.	Weight per Knot.						Remarks.
		Knots.	Copper.	Insulator, G. P.	Iron.	Jute.	Asphalt, &c.	Complete.	
			lbs.	lbs.	Tons.	Tons.	Tons.	Tons.	
Malacca and Singapore, .	1879	116	107	140	10·350	·675	1·026	12·161	Shore.
			,,	,,	2·803	·225	·554	3·692	Main.
Germany and Norway, . .	,,	251	100	125	16·524	·487	1·225	18·536	Shore.
			,,	,,	4·135	·260	·430	5·126	Main.
			,,	,,	2·375	·150	·406	3·162	,,
Mozambique and Zanzibar,	,,	631	107	140	10·350	·675	1·026	12·161	Shore.
			,,	,,	5·230	·400	·781	6·521	Intermed.
			,,	,,	2·803	·225	·554	3·692	,,
			,,	,,	·850	·050	·362	1·372	Main.
			,,	,,	·625	·187	·517	1·442	,,
Singapore and Java, . . .	,,	919	107	140	10·350	·675	1·026	12·161	Shore.
			,,	,,	5·230	·400	·781	6·521	Intermed.
			,,	,,	2·803	·225	·554	3·692	Main.
			,,	,,	1·772	·115	·500	2·497	,,
Aden and Zanzibar, . . .	,,	1908	250	250	10·350	·675	1·026	12·274	Shore.
			,,	,,	5·230	·400	·781	6·634	Intermed.
			,,	,,	3·360	·145	·616	4·344	,,
			,,	,,	·625	·187	·517	1·442	Main.
			,,	,,	1·112	·200	·367	1·902	,,

Mechanical Data of Submarine Cables—*Continued.*

Cables.	Date.	Length Laid.	Weight per Knot.						Remarks.
		Knots.	Copper.	Insulator, G. P.	Iron.	Jute.	Asphalt, &c.	Complete.	
			lbs.	lbs.	Tons.	Tons.	Tons.	Tons.	
Java and Australia, . . .	1880	1131	107	140	10·350	·675	1·026	12·161	Shore.
			,,	,,	2·803	·225	·554	3·692	Intermed.
			,,	,,	·850	·050	·362	1·372	Main.
Wanganui and Wakapuaka,	,,	108	107	140	11·402	·518	..	12·030	Shore.
			,,	,,	2·847	·145	·616	3·718	Main.
Hong Kong and Luzon,	,,	528	107	140	10·350	·675	1·026	12·161	Shore.
			,,	,,	5·230	·400	·781	6·521	Intermed.
			,,	,,	2·803	·225	·554	3·692	,,
			,,	,,	·880	·070	·451	1·511	Main.
			,,	,,	·710	·212	·518	1·550	,,
Placentia and St. Pierre,	,,	109	107	140	14·770	·625	..	15·725	3 cores.
			,,	,,	7·700	·600	·850	9·480	,,
			,,	,,	4·650	·200	·575	5·755	,,
Ireland and Newfoundland, . .	,,	1423	300	300	·860	·115	·725	1·967	Main.
			,,	,,	·720	·115	·705	1·807	,,
England and Norway, . .	,,	423	180	200	11·585	·260	1·045	13·100	Shore.
			,,	,,	7·780	·405	1·000	9·355	Intermed.
			,,	,,	3·450	·225	·662	4·507	,,
			,,	,,	2·400	·137	·570	3·277	Main.
			,,	,,	14·100	·260	1·085	15·615	

Mechanical Data of Submarine Cables—*Continued.*

Cables.	Date.	Length Laid	Weight per Knot.						Remarks.
		Knots.	Copper.	Insulator, G. P.	Iron.	Jute	Asphalt, &c.	Complete.	
			lbs.	lbs.	Tons.	Tons.	Tons.	Tons.	
Norway and Sweden, . .	1880	94	180	200	2·400	·137	·570	3·277	Main.
			,,	,,	7·780	·405	1·000	9·355	Intermed.
St. Pierre and Sydney, . .	,,	185	107	140	14·770	·625	..	15·725	3 cores.
			,,	,,	7·700	·600	·850	9·480	,,
			,,	,,	4·650	·200	·575	5·755	,,
Singapore and Batavia, . .	1881	537	107	140	10·350	·675	1·026	12·161	Shore.
			,,	,,	2·803	·225	·554	3·692	Main.
Trieste and Corfu, . . .	,,	550	130	130	10·0 0	·600	1·015	11·731	Shore.
			,,	,,	5·340	·400	·727	6·583	Intermed.
			,,	,,	2·900	·150	·587	3·753	,,
			,,	,,	1·110	·057	·371	1·654	Main.
Valentia, Greitseil, . .	1882	841	130	130	11·900	·550	·400	12·966	Shore.
			,,	,,	5·600	·350	·633	6·729	Intermed.
			,,	,,	2·78	·125	·499	3·520	Main.

SHEATHING.

Results of tests of Iron Wire used for sheathing Cables, by Clark, Forde, & Co., from a large number of averages taken between 1878 and 1882.

Name of Maker.	Description.	Size of Wire. B.W.G	Size of Wire. Dia.	Breaking Stress of Wire	Breaking Stress per sq.in	Elongation per cent.	Torsion Test. No. of turns round itself and back.	Used in Cable.
			In.	lbs.	Tons		Round. Back.	
... ...	Iron galvanised,	6	·200	2266	32	18·3	3 — 0	Duplicate Australian.
Felten & Guillaume,	Homo. iron gal.,	13	·100	1113	63	7·1	3 — 3	" "
... ...	" "	13	·100	1370	78	5·7	3 — 2½	Eastern & S. African.
Johnson & Nephew,	" "	13	098	1392	82	5·1	3 — 2½	Hong Kong, Manilla.
Felten & Guillaume,	" "	13	·099	1286	75	5·5	3 — 3	" "
... ...	" "	13	·099	981	57	4·9	3 — 3	" "
Felten & Guillaume,	Iron galvanised,	6	·200	2142	30	18·1	3 — 0	" "
Johnson & Nephew,	" "	6	·198	2052	30	19·0	3 — 0	" "
Felten & Guillaume,	Homo. iron gal.,	13	·098	1094	70	5·2	3 — 3	Atlantic, 1880.
G. F. Rogers, . . .	" "	13	·101	1038	63	3·	3 — 3	" "
Johnson & Nephew,	" "	13	·098	1384	89	4·9	3 — 3	" "
Fox & Co., ...	" "	13	·100	959	59	3·5	3 — 3	" "
Felten & Guillaume,	Steel galvanised,	13	·099	1641	102	5·7	3 — 2	" "
" "	Iron "	6	·200	2213	33	14·5	3 — 0	Placentia, Sydney,'80.
Johnson & Nephew,	" "	6	·197	2069	31	18·5	3 — 0	" "
" "	" "	8	·165	1388	30	17·8	3 — 0	... ...
Hill & Co., ...	" "	8	·160	1262	29	18·	3 — 0	... ...
Felten & Guillaume,	" "	8	·169	1531	32	15·7	3 — 0	... ...
" "	" "	4	·240	3097	32	18·	3 — 0	Placentia, Sydney,'80.
" "	" "	6	·201	2136	31	16·5	*3 — 1	Greitseil, Valentia,'82.

* The twist test is now always applied besides bending and unbending the wire round itself.

The weight per knot of 4 B.W.G. iron wire = 873 lbs. | The weight per knot of 8 B.W.G. iron wire = 450 lbs.
" " 6 " " = 622 " | " " 13 " " = 144 "

Cable Wire for Government of India.

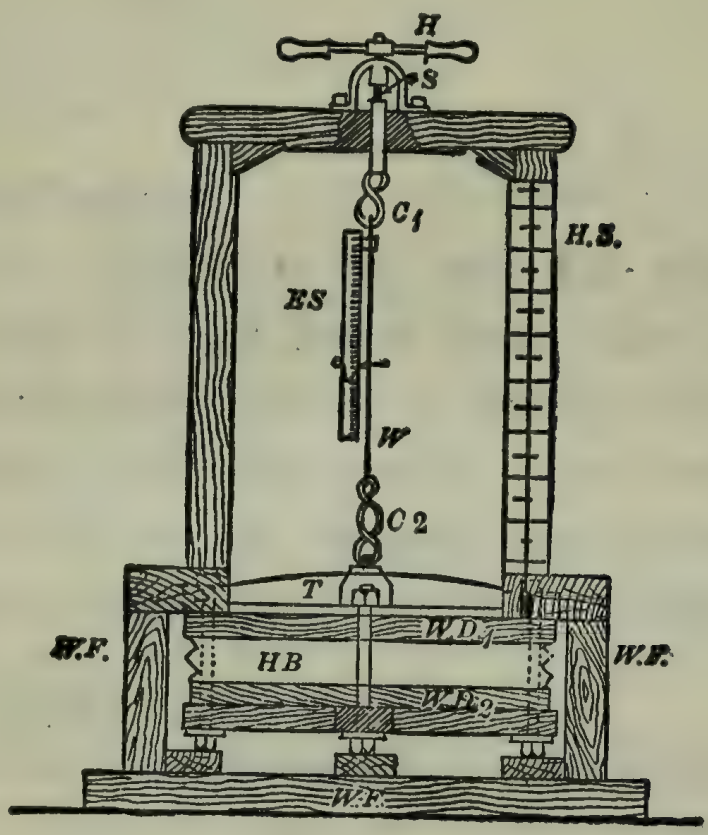
Table of Weights and Tests for Standard Sizes. (See Specification, page 240.)

Nominal Size.	Required Weight per Mile.	Corresponding Tests for Strength and Ductility.										Weight of each Coil.	
		To bear	Twists in 6 in.	To bear	Twists in 6 in.	To bear	Twists in 6 in.	To bear	Twists in 6 in.	To bear	Twists in 6 in.	Maximum.	Minimum.
		Lbs.		Lbs.		Lbs.		Lbs.		Lbs.		Lbs.	Lbs.
3½	900	3,000	10	3,075	9	3,150	8	3,225	7	3,300	6	95	105
4½	750	2,500	11	2,562	10	2,625	9	2,687	8	2,750		95	105
5½	600	2,000	12	2,050	11	2,100	10	2,150	9	2,200	8	95	105

Note I.—In order that the wire may be readily recognised as cable wire, the binders of the coils are to be ungalvanised. See Para. 16.

Note II.—No joints will be allowed in Cable Wire. See Para. 11. Specification, page 240.

Thomson's Hydrostatic Wire-Testing Machine.



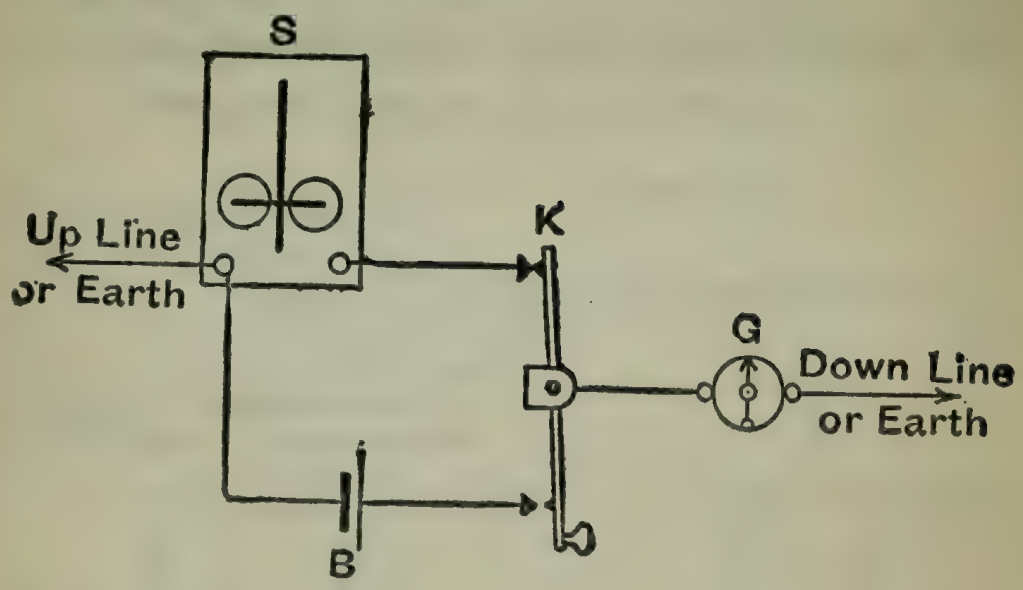
Where W represents wire to be tested fixed to C_1 C_2, top and bottom clips; H B, circular hydrostatic bellows, 3 feet diameter, with india-rubber sides; W D_2, bottom wooden disc attached to T, iron tripod connected at centre to clip C_2 while W D_1, upper wooden disc is rigidly fixed to W F, wooden framing; H, handle keyed to S, screwed spindle; H S, hydrostatic scale, consisting of a glass tube fixed into short brass cylinder; E S, scale for measuring percentage elongation. The upper end is fixed to W and lower is free.

Method of Testing Wire by Machine.

1. Turn handle backwards until C_1 is as far down as it will come.
2. Fix wire in clips, and attach pointer to be opposite zero of scale.
3. Turn handle H forward, thus lifting W D_2 stretching wire, and forcing water up H S.
4. Note the elongation by scale E S, and total tensile stress by scale H S, at the moment wire breaks. W D_2 falls upon stops, so as not to injure india-rubber bag.

The above machine was used in testing all the wire supplied for making the Western and Brazilian Company's cables. The homogeneous wire gave an average of 55 tons per square inch. See table, p. 296, where some homo iron wire gave an average of 82 tons per square inch breaking stress.

Direct Working Sounder.



B represents Battery.
K " Key.
S " Sounder.
G " Galvanometer (which may be dispensed with on very short circuits).

Note.—In India these have a mean resistance of 25 to 35 ohms, and work with four Minotto cells in series, and a current of 72 milli-amperes.

Portable Sounders, with polarised relay of 500 ohms resistance (250 each bobbin), work with 2 milli-amperes.

The resistance to give a relay $R = \frac{5}{8} L$,

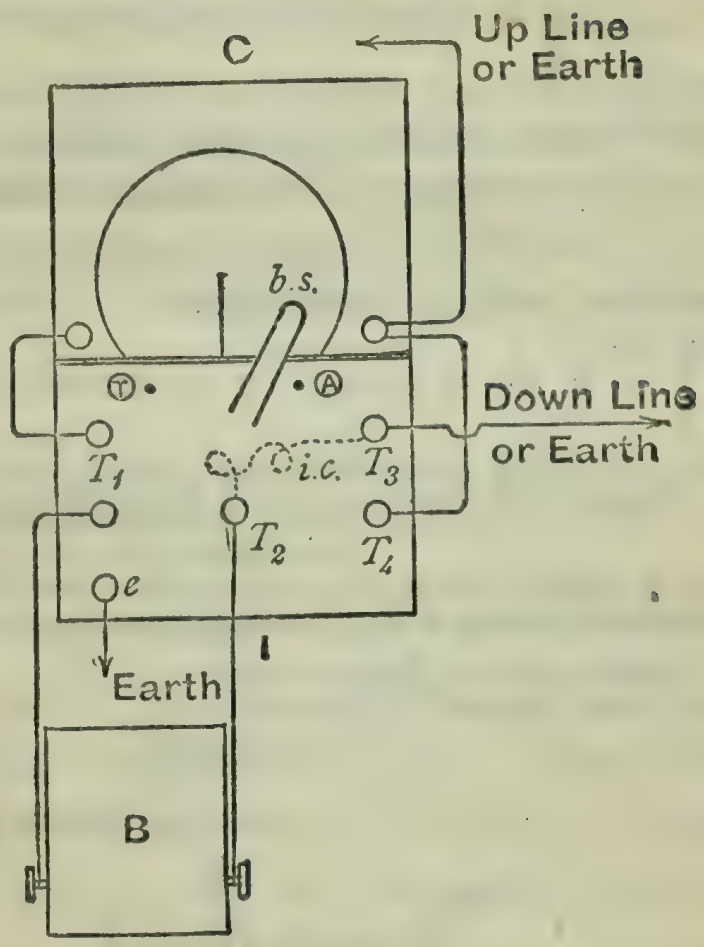
where L = resistance of the longest line on which it ought to work.

Siemens' Relays.—A Siemens' relay, r, of 500 ohms, works well with a current, C, of 2 milli-amperes. The same relay having a resistance, r_1, will work with a current $C_1 = \frac{C\sqrt{r}}{\sqrt{r_1}} = \frac{44{\cdot}8}{\sqrt{r_1}}$ milli-amperes.

This formula takes no account of the thickness of the insulator.

WHEATSTONE'S A B C.

(Viewed from behind.)



C	represents	Commutator.
I	,,	Indicator.
i c	,,	Indicator coils.
bs	,,	Bell-switch lever.
e	,,	Earth connection to lightning protector.
B	,,	Bell.
T_1, T_2, T_3, T_4,		Terminals.

Arrangements of Indicator.

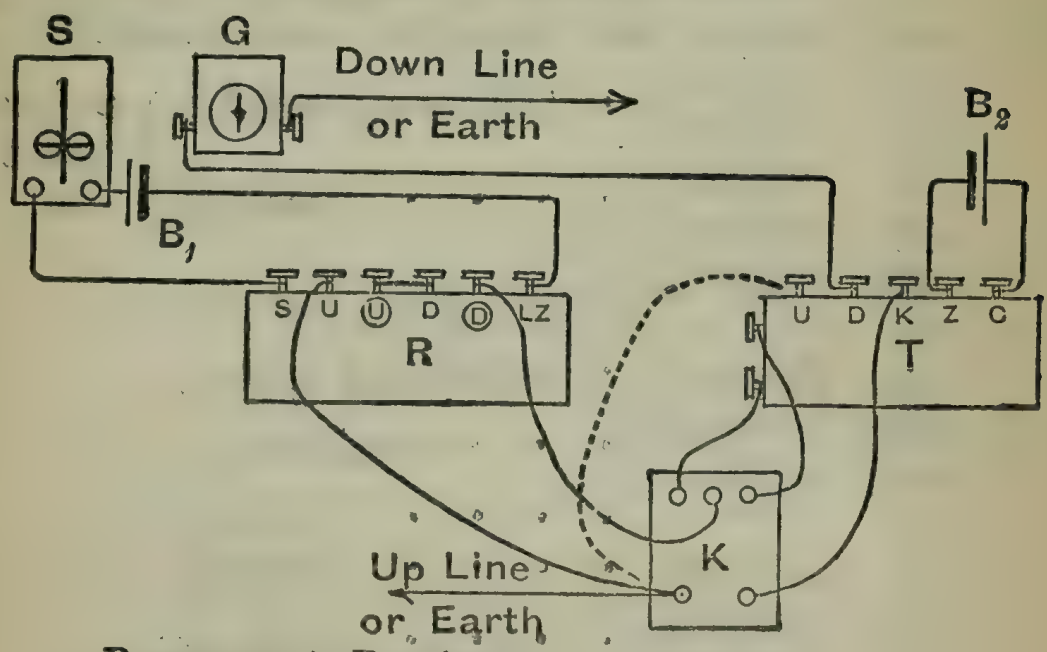
Ordinary arrangement, with bell in circuit—As in diagram.

Bell temporarily out of circuit—Lever against T.

Bell removed—Join T_1 and T_2 by brass strap.

Instrument cut out (by short circuit) during thunderstorm—Join T_3 and T_4 by brass strap.

WHEATSTONE'S AUTOMATIC.



R represents Receiver.
T " Transmitter.
K " Key.
S " Sounder.
G " Galvanometer.
B_1 " Local Battery.
B_2 " Line Battery.

Variation of Receiver Connections.

Coils in series—Brass strap joining (U) and D, as in diagram.

Coils in parallel—One brass strap joining U and (U). Another brass strap joining D and (D).

Extra Current.—To reduce the extra current in the receiver connect the bobbins in multiple arc, or connect a condenser between the instrument and earth shunted by a high resistance.

Current Required.—An ordinary Morse requires 25 milli-amperes $\left(25 \frac{\text{amp.}}{1000}\right)$ to work it; and with a polarised relay not less than 10 milli-amperes. The Wheatstone automatic requires 15 to 20 milli-amperes.

Connecting Wires.—The best wire for connecting up telegraph instruments is No. 16 S.W.G. gutta-percha covered leads.

Relative Speeds of Signalling.—

			Words of five letters per minute.
With Morse,		simplex,	25
		duplex,	45
	Hughes,	simplex,	60
		duplex,	110
	Meyer,	per key,	25
	Baudot,	,,	40
	Wheatstone,	simplex,	350
		duplex,	600
	Gray's harmonic,	per key,	35
	Delaney's multiplex,	,,	25
		hexode,	150
on short cables	Mirror,	simplex,	30
		duplex,	50
	Siphon Recorder,	simplex,	25
		duplex,	50

Electro-static capacity of aerial lines in E.S. units (Sir Wm. Thomson).

$$= \frac{l\,k}{\log \varepsilon \frac{4\,h}{d}}$$

Where l for length of line in centimetres.
,, k ,, specific inductive capacity of air.
,, h ,, height of line above ground in c.m.
,, d ,, diameter of wire in centimetres.

SIGNAL ALPHABET.

	Morse	Needle and Mirror.		Morse.	Needle and Mirror.
A	· —	⟋	J	· — — —	⟋⟋⟋
ä (æ)	· — · —	⟋⟋	K	— · —	⟋⟋
B	— · · ·	⟋ \ \ \	L	· — · ·	⟋ \ \
C	— · — ·	⟋ \ ⟋ \	M	— —	⟋⟋
D	— · ·	⟋ \ \	N	— ·	⟋ \
E	·	\	O	— — —	⟋⟋⟋
F	· · — ·	\ \ ⟋ \	ö (œ)	— — — ·	⟋⟋⟋ \
G	— — ·	⟋⟋ \	P	· — — ·	⟋⟋ \
H	· · · ·	\ \ \ \	Q	— — · —	⟋⟋ ⟋
I	· ·	\ \	R	· — ·	⟋ \

SIGNAL ALPHABET.

	Morse.	Needle and Mirror.		Morse.	Needle and Mirror.
S	···	\\\	1	·————	\////
T	—	/	2	··———	\\///
U	··—	\\/	3	···——	\\\//
ü (ue)	··——	\\//	4	····—	\\\\/
V	···—	\\\/	5	·····	\\\\\
W	·——	\//	6	—····	/\\\\
X	—··—	/\\/	7	——···	//\\\
Y	—·——	/\//	8	———··	///\\
Z	——··	//\\	9	————·	////\
Ch	————	////	0	—————	/////

PUNCTUATION

		Morse.	Needle and Mirror
Full Stop	(.)	— — —	\\ \\ \\
Colon	(:)	— — — — — —	/ / / \\\
Semicolon	(;)	— — — — — —	/ \ / \ / \
Comma	(,)	— — — — — —	\ / \ / \ /
Note of Interrogation	(?)	— — — — — —	\\ / / \\
Note of Admiration	(!)	— — — — — —	/ / \\ / /
Hyphen	(-)	— — — — — —	/ \\\\ /
Apostrophe	(')	— — — — — —	\ / / / / \
Parenthesis	( ) (P.O.)	— — — — — —	/ \ / / \ /
Inverted Comma	(" ") (P.O.)	— — — — — —	\ / \\ / \
Begin another Line	(P.O.)	— — — — — —	\ / \ / \\
Oblique Stroke ½ or ⅙	(P.O.)	— — — — — —	/ / / / / /
Horizontal Bar (½)		— — — — — —	
Call Signal		— — — — — —	/ \ / \ / \
Understand Message	(P.O.) Its code name.	— — — — — —	\\\ / \
Correction, or rub out	(P.O.)	— — — — — —	\\\\\\\\
End of Message		— — — — — —	\ / \ / \ / \
Wait		— — — — — —	\ / \\\
Cleared out, and all right	(P.O.) (P.O.)	— — — — — —	\ / \\ / \\ / \

RULES FOR SPACING.

The length of a dot being taken as unit.
1st. A dash is equal in length to 3 dots.
2nd. The space between the elements of a letter is equal to 1 dot.
3rd. The space between two letters of a word is equal to 3 dots.
4th. The space between two following words is equal to 6 dots.

Materials for Telegraph Lines.—Average stores for erecting 1 mile (No. 11 G.I.) on roads. —Twenty poles, varying in length from 20 to 30 feet, twenty G.I. roofs, eighteen saddles, 4 lbs. 3-inch nails, two 24-inch arms, two $7\frac{1}{4}$-inch bolts, or two eye-bolts for shackles, eighteen Z insulators, eighteen hoop guards, four Bright's shackles, eight $4\frac{1}{2}$ bolts, eight 8-inch straps, 1 cwt. 3 qrs. 15 lbs. No. 11 G.I. wire, 2 lbs. No. 8 G.I. wire, 2 lbs. solder, 8 lbs. No. 8 G.I. wire for stays, two stay rods and blocks.

For laying 1 mile of single underground line. —1760 yards of iron pipe, flush boxes and bends according to the route, the former in general about every 100 yards, the latter according to the turnings and corners to be passed; 1760 yards of No. 7 or No. 3 prepared G.P. wire; Chatterton's compound, sheet gutta-percha, resin, solder, according to the joints required.

Breaking Stress—Wooden Poles.—See *The British Association Report* for 1885, or *The Electrician*, September 18, 1885, for Mr. Preece's paper on the strength of round timber.

Telephones.

Transmitters.—The resistance of the Blake transmitter varies with adjustment from $\frac{1}{10}$ to over 100 ohms. Speaking is good with 9 to 10 ohms. The Blake induction coil has an average resistance of 0·5 ohm in the primary wire, and 250 ohms in the secondary.

The Ader transmitter has a resistance of 5 ohms; the primary wire of 1·5 ohms, and the secondary of 150 ohms.

The Hunnings transmitter has a resistance of

15 ohms. The Dolbear transmitter, used with the Dolbear static receiver, has a primary wire of ·2 ohms, and a secondary of 1200 ohms. The change of resistance on the transmitter contact should considerably affect the resistance of the primary circuit.

The De Jongh transmitter has a resistance of 5 ohms in the microphone, ·2 ohms in the primary, and 150 ohms in the secondary. The Berliner transmitter has a resistance of 4 to 10 ohms in the microphone, ·89 to 1 in the primary, and about 160 in the secondary.

Receivers.—Resistance of the Bell receiver used with the Blake transmitter, 70 ohms. Resistance of the Ader receiver used with the Ader transmitter, 75 ohms.

Speaking Batteries.—In towns one No. 2 Leclanché cell is used with the Blake. For calls a 4 to 6 cell Leclanché battery, or small magneto-electric machine, are used in exchanges. A magneto call is used on private lines. With the Ader, 3 agglomerate Leclanché cells are used, and 6 with the Hunnings. With the Dolbear, 6 agglomerate Leclanché's are used for an ordinary mile circuit, and an extra cell added for every two miles beyond.

Leading in Wires for Telephone Circuits.—No. 18 S.W.G. copper wire insulated with two coatings of G.P., bringing the diameter to No. 7 S.W.G., the whole wound with tarred tape. Paint is injurious to G.P.

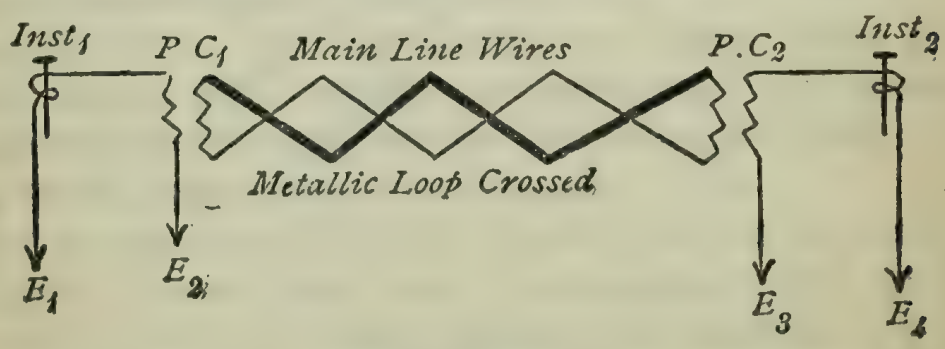
Joining up wires consist usually of No. 20 S.W.G. copper wire in thread covering, or No. 18 covered to No. 12 with G.P.

Exchange Earths.—A copper wire, No. 8

S.W.G., soldered to both water and gas pipes on the street side of the meter. A pump pipe leading into a well serves, so also does a strip of lead 5 feet long by 6 inches wide (weighing about 4 lbs.), and buried in the centre of a heap of coke in a hole 4 feet deep in moist soil. Earth connections are tested by ringing the bell.

Lightning Arresters should be connected to the "earth" by No. 16 wire. A simple arrester which permits of working consists of two pieces of No. 16 double silk covered wire, each 6 inches long and of different colours, twisted together. They are tested to see that there is no leakage from one to the other, and connected one to a terminal of the board and the other to the "earth" wire.

Anti-Induction Circuit (*Preece and Hughes*).



Index to Diagram.

When *Inst.* = Telephone instruments and call bells complete.

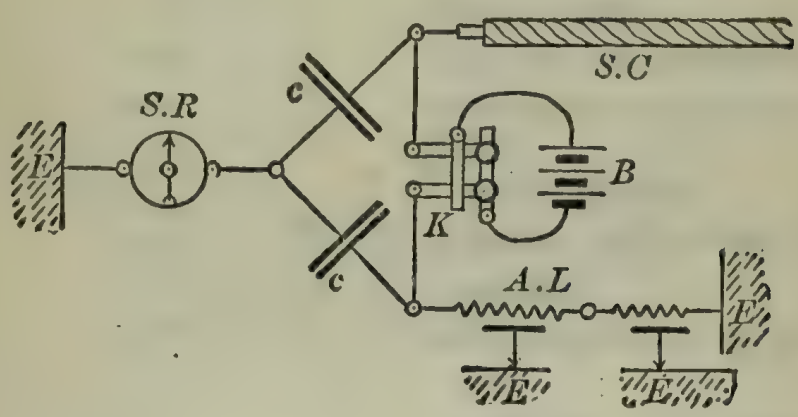
PC_1 and PC_2 = Circular flat, parallel coils of fine wire with or *without* any soft iron core placed in the exchanges at each end.

E_1, E_2, E_3, E_4 = Earths.

The forward and return main line wires must be crossed in order to prevent induced currents from neighbouring wires. One crossing every 4 spans is usual.

Submarine Cables.

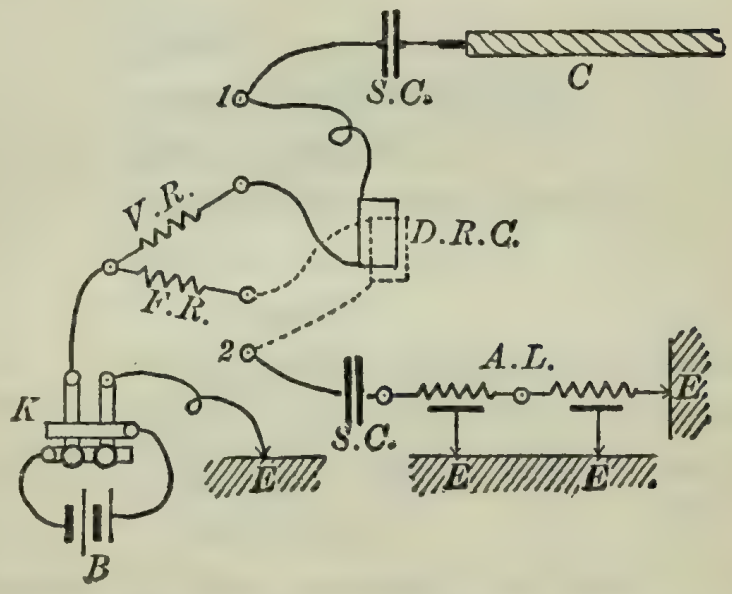
Duplex with Condenser in Bridge Arms.—



SR	represents	Siphon Recorder or other receiving instrument.
cc	„	Condensers about same capacity as used in ordinary simplex signalling with small subdivided condenser for adjusting.
SC	„	Submarine Cable.
AL	„	Artificial Line (Muirhead's).
K	„	Signalling Key.
B	„	Battery (well insulated).
E	„	Earth.

The above method has been used on short cables and gives good results. Muirhead's 'double-block' for long cables is the same with *K* and *SR* transposed. The station at other end of cable is joined up in the same way.

Duplex on Atlantic Cables (Valencia—Newfoundland).

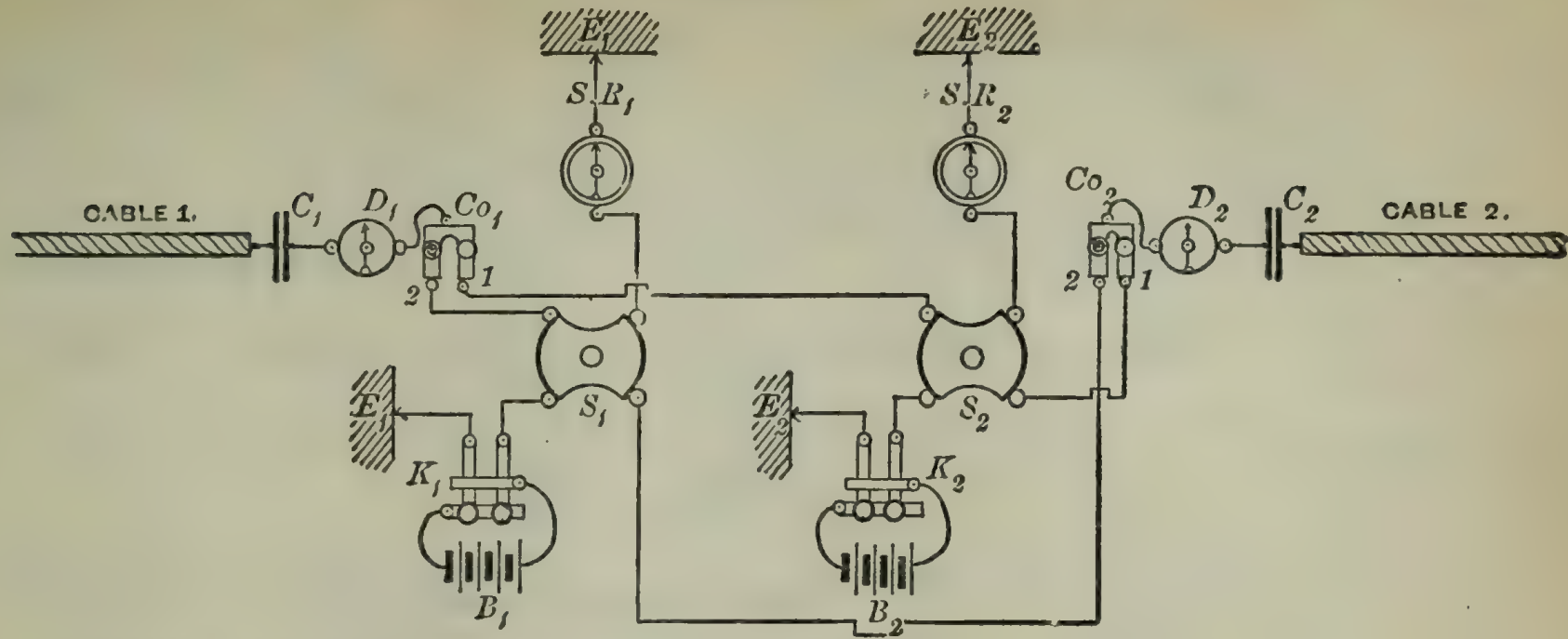


Where *D R C* represents	a	differentially wound Siphon recorder coil 250 ohms each coil.
F R	"	fixed resistance of Wheatstone bridge.
V R	"	variable resistance of Wheatstone bridge.
C	"	cable.
S C	"	signalling condensers.
A L	"	artificial line (Stearns').
K	"	sending key.
B	"	" battery.
E	"	earth.

The circuit is always open to receive, and therefore no sending signals are recorded, and no sending shunt required. A receiving shunt is introduced between terminals 1 and 2 when required.

Simplex Translation and Simplex Sections on Submarine Cables.

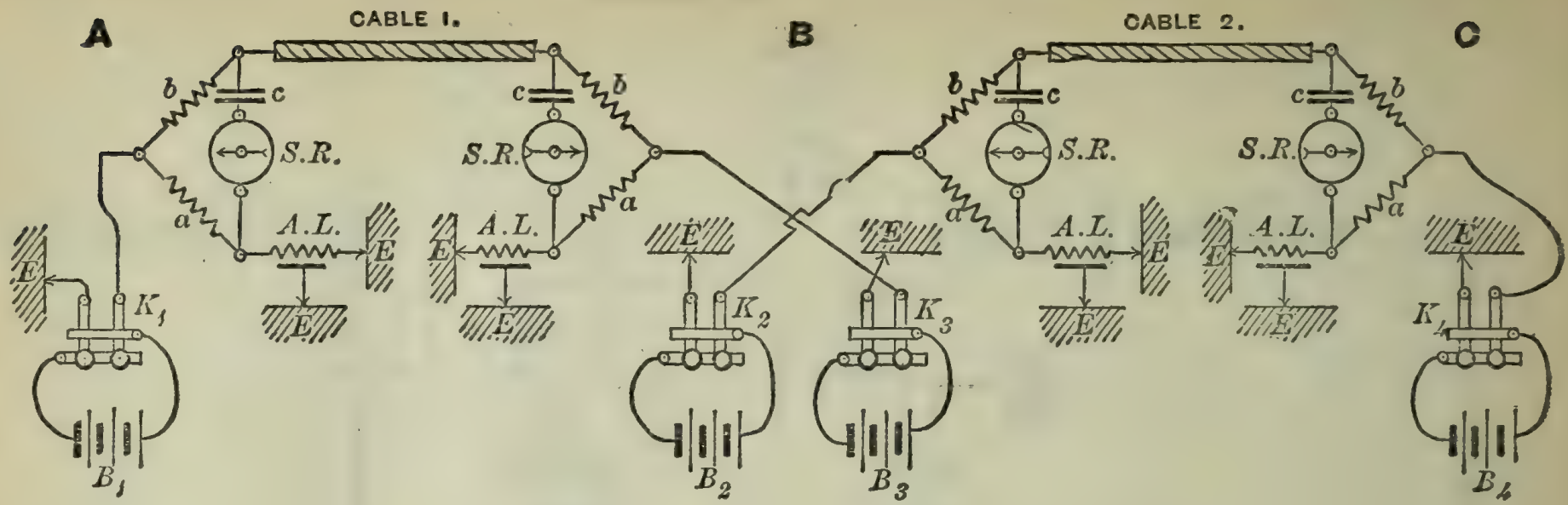
(B. Smith.)



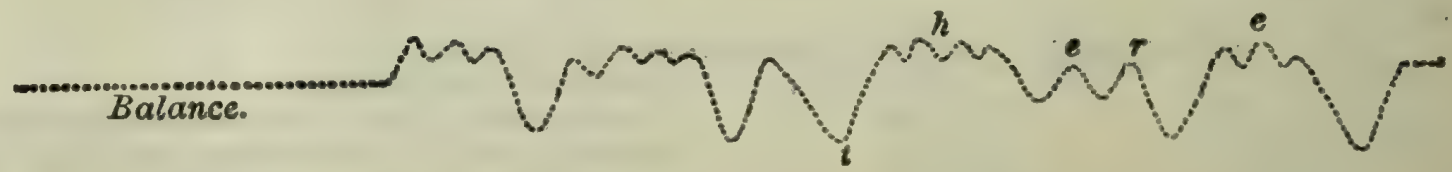
Where cable 1 and 2 represent the two cables.

C_1, C_2	,,	signalling condensers.
D_1, D_2	,,	galvanometer detectors for sending currents.
Co_1, Co_2	,,	commutators for switching from the one system to the other.
$S R_1, S R_2$	,,	Siphon Recorders (or mirrors).
$S_1 S_2$	,,	switches for turning to send and receive.
K_1, K_2	,,	sending keys.
B_1, B_2	,,	,, batteries.
E_1, E_2	,,	separate earths.—(See p. 314, for directions.)

Duplex Translation on Submarine Cables.—(*B. Smith.*)



Siphon Recorder Signals



Photographed from actual signals taken by A. Jamieson, at Alexandria. Signalling from Marseilles by Muirhead's Bridge Duplex as above.

Directions for Working Simplex Translation, &c.—(See p. 312.)

For translation from cable 1 to cable 2, using recorder, $S\,R_1$, have connections as shown in diagram, with plugs in No. 2 holes of Co_1 and Co_2. To translate from cable 2 to cable 1, turn switch, S_1, round. For translation with recorder, $S\,R_2$, put plugs in No. 1 holes of commutators, Co_1 and Co_2. For simplex put plug in hole 2 of commutator, Co_1, and in hole 1 of commutator, Co_2. When many locals are not expected at an intermediate station, simplex translation increases power of transmitting traffic about 75 per cent. over old form of simplex and writing down messages and re-sending them.

Duplex Translation Connections.—(p. 313).

For working two long Cables with Sir William Thomson's Recorder.

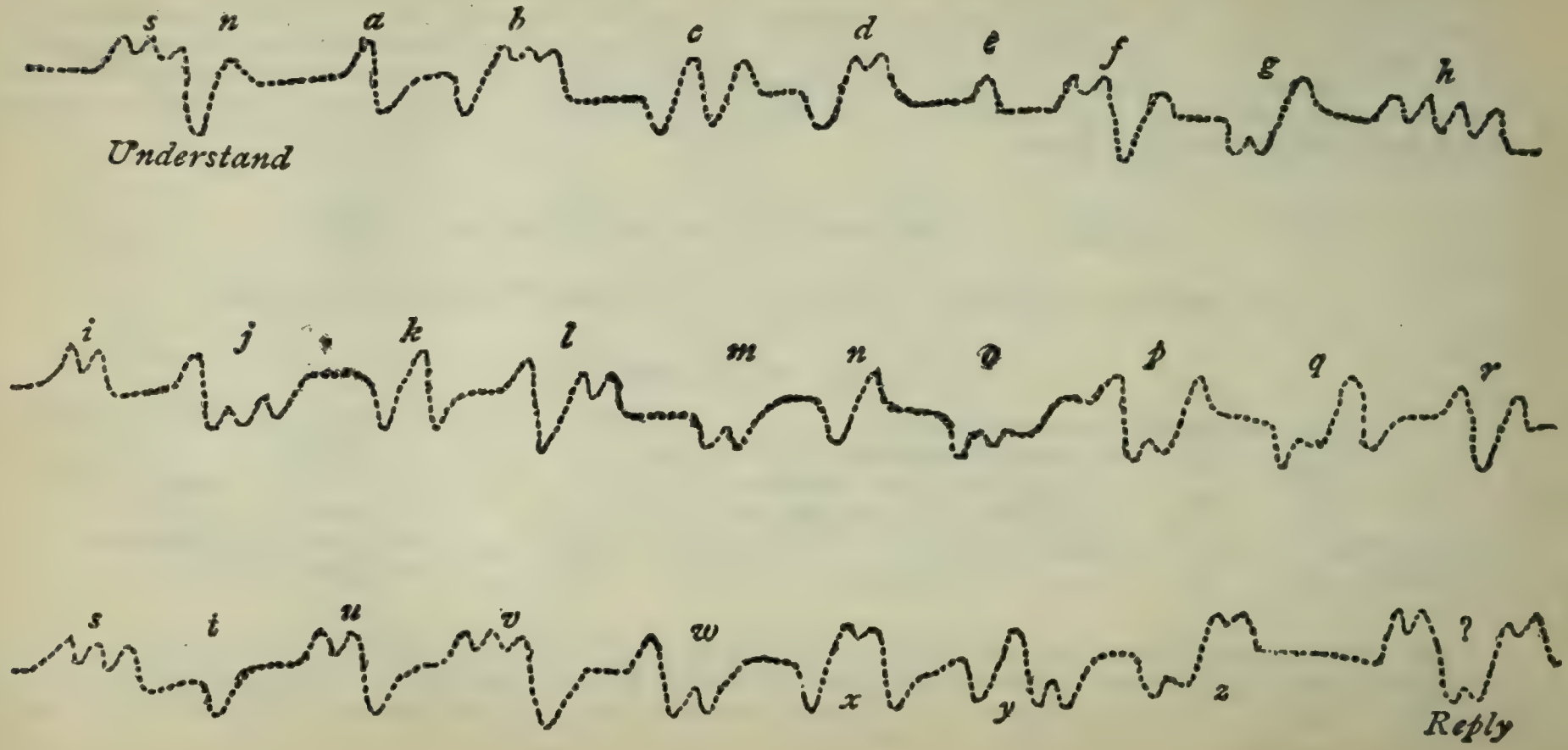
Index to Diagram.

A & C	represent	extreme stations.	*a* & *b*	represent	arms of Wheatstone's bridge.
B	,,	intermediate station.	*A L*	,,	artificial line (Muirhead's).
S R	,,	Siphon Recorder, or other recording Instruments.	*C*	,,	receiving condensers.
K_1, K_2, K_3, K_4,	,,	sending keys.	*E*	,,	earths.
B_1, B_2, B_3, B_4,	,,	,, batteries.			

The above method, well carried out, is capable of accomplishing nearly three times as much traffic as can be done by ordinary simplex working between stations, A and C, with intermediate one, B. The two operators at station B, simply send the signals as they appear on their slip, but can break in at any time to send locals.

SIPHON RECORDER SIGNALS.

Alphabet, photographed from Signals received at Pernambuco, by A. Jamieson, on the Pernambuco-St. Vincent Cable, 1844 Knots.



Best Resistance for Receiving Instrument.—To determine the best resistance of galvanometer or recorder coil for receiving signals on a submarine cable, with signalling condensers placed at each end of line, the following formula by Hockin is useful:—

$$r = \frac{0{\cdot}64\ \mathrm{R}}{\sqrt{\mathrm{S} \cdot \mathrm{R} \cdot \mathrm{K}}}\ \text{ohms.*}$$

where r = resistance of receiving instrument.
R = total resistance of conductor in *megohms.*
S = speed in words per minute likely to be usually sent on line.
K = total capacity of cable in microfarads.

From this it appears that for a cable of given working speed, the resistance of the galvanometer should be proportional to the resistance of the conductor; thus, the best galvanometer for a line with a core of 400 lbs. copper per knot, has a much lower resistance than one best for a core of 107 lbs. per knot, the theoretical speed of the two lines being the same.

Speed of signalling through long submarine cables, with the Siphon Recorder and mirror galvanometer.

$$\mathrm{S} = c\,d^2\,\frac{\log.\ \mathrm{D} - \log.\ d}{l^2}$$

$$= c\,70{\cdot}4\,w\,\frac{\log.\ \sqrt{70{\cdot}4\,w + 491\ \mathrm{W}} - \log\ \sqrt{70{\cdot}4\,w}}{l^2}$$

* See *Soc. Tel. Engineers' Journal*, Vol. V., p. 439, for other cases by Hockin.

Where

S = Speed in letters per minute.	W = weight of dielectric in lbs. per knot.
D = diameter of dielectric in mils (·001 inch).	w = weight of conductor in lbs. per knot.
d = diameter of conductor in mils (·001 inch).	l = length of cable in knots.

c = a constant determined by experiment = 28,000, from a number of experiments on cables with Willoughby Smith's improved guttapercha, and with 95°/₀ purity of copper conductor.

E.g. Using the data for the Ireland-Newfoundland cable, given at Table, p. 248, we get S = 105 letters per minute.

The constant, c, for ordinary guttapercha, or any other form of dielectric, will be in the inverse ratio of its electro-static capacity per knot to that of W. Smith's. (See Index.)

If R = the total resistance of the cable conductor in ohms, as measured after submersion, and K = the total capacity in microfarads.

Then $S = \frac{c_1}{R \cdot K}$ (in letters per minute).

Where c_1 = a constant determined by experiment = 36×10^7, from a number of experiments with W. Smith's core, with 95°/₀ purity of conductor. Testing the above-mentioned Ireland-Newfoundland cable, by this formula S = 106 letters per minute.

Speed on the Jay Gould Cables (*Dr. Muirhead*), March 29, 1883.—A thousand code words were sent from Penzance to Canso, in eighty-one minutes, including all repetitions and collations. They contained 7,288 letters, equivalent to 1,458 words of 5 letters each. The rate of transmission is therefore eighteen words of five letters per minute, ordinary or "simplex" working. With "duplex," the rate of transmission is practically doubled. Dimension of above cable.

No. 1. Penzance, Cornwall to Cape Canso, Nova Scotia; length 2,518 knots, total resistance at 75° F. = 8,320 ohms, total capacity = 939 microfarads.

Time of Transmitting a Signal (*R. Sabine*).—The time in seconds, t, required for a signal to form at the end of a cable is,

With the Morse $t = \frac{414}{109} Kr$ seconds.

" Hughes $= \frac{105}{109} Kr$ "

" Mirror $= \frac{47}{109} Kr$ "

Where K = total capacity of cable in microfarads.
r = resistance of conductor in ohms.

The speed depends on the inertia of the instrument and the retardation in the cable.

Limit of Speed.—Automatic senders have not proved as yet very successful on cables, and as

the average working limit of speed of a good telegraphist is 135 letters per minute with the Siphon Recorder, a submarine cable need not be designed, according to the above formula, to exceed this in carrying capacity.

Duplex increases the total carrying capacity by about 90°/₀, and manual translation on two sections along with duplex by about 150 °/₀, but manual translation on three sections is not successful.

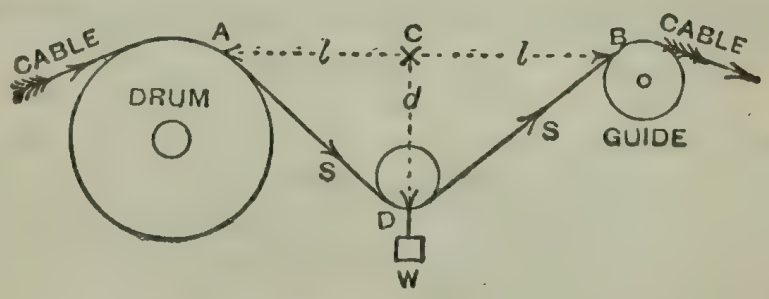
Words per Minute.—In estimating the speed of signalling in words per minute, the number of letters to the word should always be stated to prevent ambiguity. Hitherto it has been usual to take the length of a word as five letters, but from the mean of a large number of telegraph messages, it has been found that seven letters go to the word.

The Speed with Mirror Galvanometer, if worked by mirror clerks of the highest ability, is slightly greater than that with the Siphon Recorder, but the average is about the same. Preference is now universally given to the recorder, on account of its many advantages—such as permanent record of signals, fewer and less skilled clerks required, and it is much less trying to the eyes of the operator than the mirror system.

The Morse Recorder, when worked with cables, has a speed of about $\frac{1}{14}$ that of the Siphon Recorder. It can, therefore, be used only with short cables of, say, under 400 knots (with $w = 107$ lbs. and $W = 140$), but if worked in connection with the Brown-Allan relay, the speed is increased, and it may be advantageously used with longer cables.

Stress on a Cable.—To indicate the stress on a submarine cable during laying or picking up, or on a grapnel rope by the ordinary dynamometer, attach an index or pointer to the cross-head or sliding block of the dynamometer, and place behind it a scale, calculated for cwts., by one or other of the following formulæ, according to circumstances:—

In order that the friction between the dynamometer, cross-head, and its guides, shall be a minimum, the dynamometer, D, *must* be placed midway between the point, A, where the cable bears on the paying-out or picking-up drum, and the point, B, where it bears on the guide-pulley next to the stern or bow sheaves, and these bearing points, A, B, should be in a horizontal line.



Let S = stress on cable or rope (in cwts.) to be found.
W = weight of all the moving gear (in cwts.)
l = distance A C or C B (in inches).
d = deflection of cable from horizontal (in inches).

Then by the parallelogram of forces

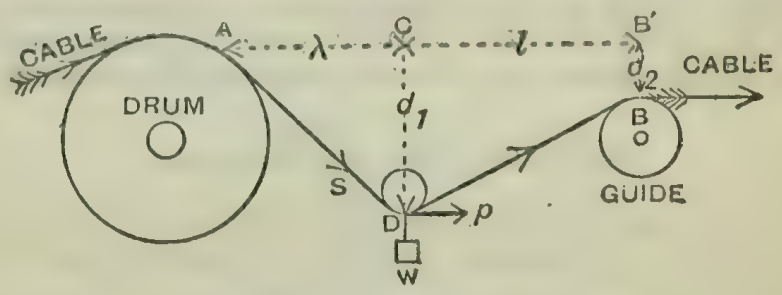
$$S = \frac{W\sqrt{l^2 + d^2}}{2d} \text{ (cwts.)}$$

$$\therefore d = \frac{W l}{\sqrt{4S^2 - W^2}} \text{ (inches).}$$

Since the stresses and deflections of the cable are in inverse ratio to one another, and W and l are constant, it is only necessary to work out one example for d; plot it off on the dynamometer scale, and mark the others in the inverse ratio, —*i.e.*, for double the stress half the deflection, and so on.

If the points, A and B, are not in horizontal line, and the dynamometer, D, not midway between them, then the cal-

culation becomes more complicated, as fully explained and worked out by M. Lacoine in *Engineering*, Feb. 13, 1885, p. 174.



Let S and W = same as before (in cwts.)
p = horizontal pressure on guides of D (in cwts.)
λ = horizontal distance A C.
l = " " C B′.
d_1 = deflection C D (in inches).
d_2 = vertical height B B′ (in inches).

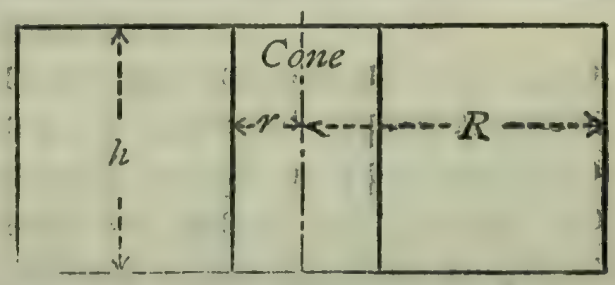
Then
$$S = \frac{W}{\dfrac{d_1}{\sqrt{d_1^2 + \lambda^2}} + \dfrac{d_1 - d_2}{\sqrt{(d_1 - d_2)^2 + l^2}}}$$

and
$$p = S\left(\frac{l}{\sqrt{(d_1 - d_2)^2 + l^2}} - \frac{\lambda}{\sqrt{d_1^2 + \lambda^2}}\right)$$

If, however, the points A and B are in horizontal lines—*i.e.*, $d_1 = d$, and $d_2 = 0$, but D not midway between them.
Then
$$S = \frac{W}{\dfrac{d}{\sqrt{d^2 + \lambda^2}} + \dfrac{d}{\sqrt{d^2 + l^2}}}$$

When $\lambda = l$ the case on p. 320 holds good.

To find the capacity of a Circular Tank.



Let r = radius of the eye in feet.
R = radius of the tank "
h = height " " "
d = diameter of the cable in feet.
n = number of coils in one flake.

Then

$$n = \frac{R - r}{d} \quad . \quad . \quad . \quad . \quad . \quad (1.)$$

Length of the first coil $2\pi\left(r + \frac{d}{2}\right)$

Length of the nth coil

$$2\pi\left\{r + \frac{d}{2} + (n-1)\,d\right\}$$

Summing this arithmetic series,

$$\Sigma l = \left\{2\pi\,(2r + n\,d)\right\}\frac{n}{2}$$

by substituting for value of n in equation . . (1.)

Length of one flake $= \frac{\pi}{d}(R^2 - r^2)$ . . (2.)

Capacity of tank per foot of height

$$= \frac{\pi}{d^2}(R^2 - r^2) \quad . \quad . \quad . \quad (3.)$$

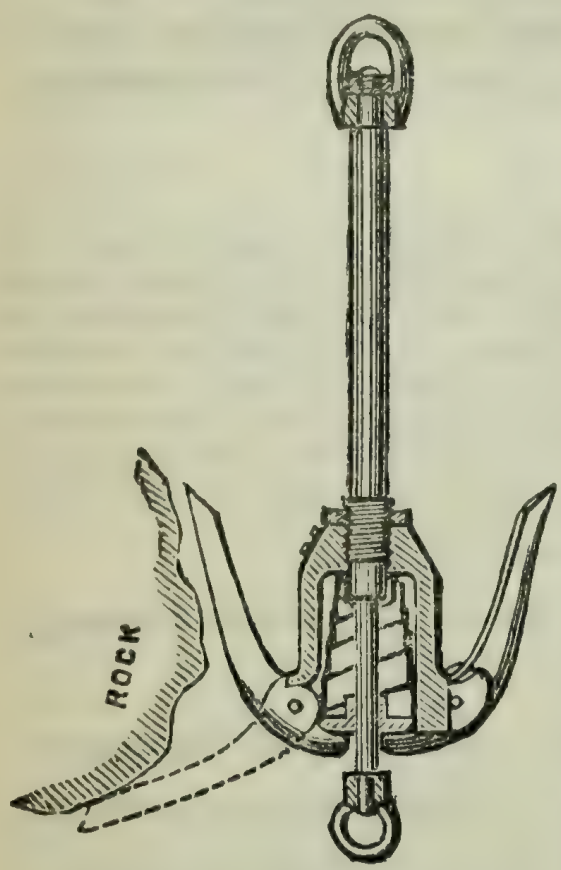
Total capacity of tank for cable

$$= \frac{\pi h}{d^2}(R^2 - r^2) \quad . \quad . \quad . \quad (4.)$$

Note.—From this result we have always to subtract a certain percentage for feather edge, and good or bad coiling. This constant varies with the kind of cable, size of tank, &c., and can only be accurately known after a few trials. For deep-sea flexible type well coiled in a tank of from 30 to 40 feet diameter, take off 5 per cent. for feather edge, &c.; for intermediate type, 10 per cent.; and for heavy shore end, about 15 per cent. Engineers usually keep a record of the capacity of their tanks per foot of height for different types, or per flake.

Grappling.—Success in grappling for cables greatly depends upon *slowly* and *steadily* dragging the grapnel over the cable ground at right angles to the line of cable ($1\frac{1}{2}$ to 2 knots an hour being a good working speed), with just sufficient slack of grapnel rope, length and weight of chain, as well as weight of grapnel, to prevent the latter from jumping, and thus missing ground. A compound steel-wire-manilla grapnel rope (4 by 5), capable of bearing a strain of 15 tons before breaking, joined up in 200 fathom

lengths, and 15 fathoms of $\frac{7}{8}$ inch chain, with a $2\frac{1}{2}$ cwt. grapnel, forms a good combination for depths up to 800 fathoms. For greater depths, a lighter compound steel-manilla rope, or one entirely of the best manilla, may be used with advantage.* On hard rocky bottom, much time, trouble, and breakage of grappling gear will be saved by using a grapnel with automatically self-relieving prongs, as in the fig. One form is shown where, on coming in contact with a rock, the longer, or searching prongs give way until the rock is passed, but upon hooking the cable it slips into a well-rounded fillet, formed by shorter prongs, and remains there until elevated to the surface.†



Cooling mixture for cable joints (gutta-percha), used on board cable ships in tropical climates:—Muriate of ammonia 5 parts, saltpetre 5 parts, water 16 parts; immerse joint and stir mixture well until joint cools.

* Except for, say, 200 fathoms next grapnel, where it might become chafed on bottom.

† See "Cable Grappling," Jamieson, *Jour. Soc. Telegraph Engineers*, vol. viii. See table for necessary Cable Stores, p. 327.

List of Electrical Instruments, &c., Required in Connection with a Cable-Repairing Steamer.

Testing Instruments for Use on Board Ship.

1. Iron-clad marine galvanometer 30,000 ohms, with 2 sets of coils (one coil 6,800 ohms at 60° Fah.) with 2 spare mirrors suspended in frame.
1 Do., do., 6,800 ohms at 60° Fah. with 2 spare mirrors suspended in frame.
2 Small resistance boxes, suitable for increasing resistance of galvanometers to 7,000 ohms.
2 Sets lamps and scales complete for galvanometers.
2 Short circuit keys for galvanometers.
2 Thomson galvanometer reversers (to obtain deflections in one direction).
1 Megohm box, with temperature marked, at which it is correct, and coefficient for temperature.
1 Muirhead's circular form of shunt-box adjusted to suit galvanometers at 7,000 ohms.
2 Wheatstone's bridges, by Elliot, 1 dial pattern, with temperature and coefficient marked.
1 Set of Thomson & Varley's circular slide resistance coils.
200 Cells (De la Rue's chloride of silver).
1 Large battery commutator.
2 Battery reversing keys, Law's pattern.
1 Tablet for leading in wires, 10 double terminals.
1 Two-way plug switch.
1 Standard condenser, ·1 to 1 microfarad capacity.
2 20 microfarad-signalling condensers.
1 Lambert's key for Thomson's capacity test.
1 Standard thermometer (certified).
6 Ordinary thermometers for tank use.
1 Good clock for testing room with seconds-hand.

Speaking Instruments for Use on Board Ship.

1 Mirror galvanometer, fitted with cushioning chambers, having 3 coils, 1,000, 4,000, and 5,000 ohms, with radial switch on galvanometer.

1 Lamp and scale for do. 1 Morse ink writer, with key.
1 Relay (Siemens').
1 Mirror-sending key and switch combined (Saunders-Jamieson).
25 Leclanche or chloride of silver cells.
2 Vertical detectors.

Testing and Speaking Instruments for Use at Cable Huts, &c.

1 Portable dead-beat (Thomson's) galvanometer in case, with 3 coils, 1,000, 2,000, and 2,800 ohms, with switch on back, with Muirhead's circular shunt-box.
1 Small resistance-box, suitable for increasing resistance of galvanometer to 7,000 ohms.
1 Lamp, scale, and paraffin holder complete for galvanometer.
1 Megohm box, with temperature at which it is correct, and coefficient for temperature
1 Wheatstone's bridge, by Elliot, with temperature and coefficient marked.
1 Battery key, Law's pattern.
1 Short circuit key for galvanometer.
1 Galvanometer reverser.
50 Chloride of silver cells in case.
1 small battery commutator.
1 Mirror-speaking galvanometer, with key, lamps, and scale, same as on board ship.
1 Small Morse writer.
1 Pair hand telephones for land-line work.
The above instruments should be fitted into 2 or 3 strong portable cases for taking ashore easily in boats.

Spare Material, &c.

1 Mechanician's tool-box, fitted with all necessary appliances for repairing electrical instruments, spare mirrors, silk, &c., &c., and including miniature lathe or watchmaker's throw.
2 Jointer's boxes complete, with materials for cooling joints. See index for receipt. (If repairing india-rubber or Hooper's core, have them specially fitted.)
1 Jointer's trough. 3 Rolls G.-P. 1 Acid pourer.
12 Gallons paraffin oil. 6 Gallons best wood naphtha.
2 Gallons methylated spirits. 10 lbs. best paraffin wax.
1 lb. best shellac. 1 roll wick for galvanometer lamps.
3 Doz. binding screws, with double terminals, assorted.
A few sheets and sticks of best insulating ebonite, assorted.
500 Yards best insulating taped leading wire for tank use.
200 Yards G.-P. connecting wire for instruments.

List of Engineering Stores, Cable Department, Required on Board a Repairing Steamer.

* Articles.	Quantity.	Description.
Grapnel Rope, . .	4600 fms.	4 × 4 in 200 fm. lengths, with links, swivels, and shackles.
Manilla ,, . .	2000 ,,	$3\frac{1}{2}''$ in 4 lengths.
Buoy ,, . .	4000 ,,	3 × 3 in 200 fm. lengths, with links, swivels, and shackles.
,, ,, . .	150 ,,	7 strand in 3 lengths.
Coir ,, . .	300 ,,	6″.
,, ,, . .	300 ,,	4″.
Manilla ,, . .	240 ,,	Tarred $4\frac{1}{2}''$.
,, ,, . .	100 ,,	,, $3\frac{1}{2}''$.
,, ,, . .	100 ,,	,, $1\frac{1}{2}''$.
Hemp ,, . .	100 ,,	$2\frac{1}{2}''$.
Cable-stoppers, . .	1 doz.	... ...
Rope-ladders, . . .	6	... ...
Buoys, ...	11	Different shapes and sizes to suit depths to 2000 fms.
,, staves, . . .	1 doz.	
,, flags & beacons,	1 ,,	
Mushroom anchors,	2	4 cwt.
,, ,,	3	3 ,,
,, ,,	3	2 ,,
,, ,,	1	$1\frac{1}{2}$,,
Grapnels, ...	2	Jamieson's with spare toes (see p. 323).
,, ...	2	Long-toed, 3 cwt.
,, ...	4	Short-toed.
,, ...	4	Centipede.
,, ...	3	Boat grapnels, 40 lbs.
,, ...	3	,, ,, 28 ,,
Chain, ...	50 fms.	$\frac{7}{8}''$ in 10 fm. lengths.
,, riding, . . .	100 ,,	$\frac{3}{4}''$ in 15 ,,
,, ,, & bridle,	200 ,,	$\frac{5}{8}''$ in 15 ,,
,, ...	150 ,,	$\frac{1}{2}''$ in 15 ,,
Slip thimbles, . . .	1 doz.	... ...

* The quantity varies with the nature of the repairing expedition and the time the steamer is likely to be absent from a port where the necessary stores can be procured. The above is a list compiled from what was supplied to a steamer for South American waters, and others for foreign stations.

Engineering Cable Stores—*Continued.*

Articles.	Quantity.	Description.
Links & swivels, . .	15	4×4.
,, . .	20	3×3.
,, & links,	6	For 6″ coir rope.
Links and thimbles,	10	1⅛″.
,, ,,	10	4″×4″.
,, ,,	9	3″×3″.
Shackles, ...	10	No. 1.
,, ...	60	No. 2, ⅞″.
,, ...	30	No. 3.
,, ...	50	No. 4.
,, ...	20	No. 5.
,, ...	5	1½″ mushroom.
,, ...	40	For 3×3. ⅝″.
,, keys, . .	12	Assorted.
,, rolling, . .	4	... ...
Blocks, wooden, and tackles, ...	8	Single, 2, 10″, and 6, 6″.
Blocks, wooden, and tackles, ...	8	Double, 2, 10″, 6, 6″.
Blocks, snatch, . .	6	... ...
,, old man, . .	2	... ...
,, iron, . . .	12	... ...
Woodhearts, . . .	12	Fitted.
Beamclips, ...	½ doz.	... ...
Cutters.	10	16″, 14″, and 10″.
Files, cable, △ & ⌓,	3 doz.	14″, assorted.
Saws for iron, . . .	4 ,,	... ...
Emery-cloth, . . .	3 ,,	Sheets, assorted.
Saws, hack blades, .	4 ,,	16″.
,, cable, frames,	6 off.	For 16″ blades.
Mallets, splicing, . .	1½ doz.	Wood, 1 doz. Iron, ½ doz.
Hammers, ,, . .	6	... ...
Knives, sheath, . .	2 doz.	... ...
Spindle riggers, . .	1 ,,	For fair leads.
Axes, ...	2 ,,	... ...
Pickaxes & shovels,	½ doz. each,	... ...
Pinchbars, ...	½ doz.	... ...
Pliers, cutting, . .	1 ,,	Assorted, 6″ to 8″.
Drawknives, . . .	2 ,,	... ...
Prickers, ...	2 ,,	... ...
Cold-chisels, . . .	6 ,,	... ...
Spanners, shifting, .	3	... ...
Tongs, splicing, . .	1 doz.	... ...

Engineering Cable Stores—*Continued.*

Articles.	Quantity.	Description.
Tongs, sleeking, . . .	½ doz.	... ...
Splicing plates, . .	3	... ...
Wire, lapping, . . .	5 cwt.	... ...
Thread, ...	2 coils,	12′ and 9′.
Yarn, spun, . . .	6 coils each,	4 yarn, 3 yarn, and 2 yarn.
Waste, white, . . .	1 cwt.	... ...
Saws, crosscut, . .	2	... ...
,, hand, . . .	2	... ...
Marline-spikes, . .	6	... ...
Dynamo machine, .	1	... ...
Lamps, arc-electric, with focussing gear,	3	Spare globes&carbons.
,, silber, . . .	6	With 50 spare chimneys and 1 spanner.
,, masthead, red,	3	... ...
,, tricolor, . .	2	Red, white, and green.
,, buoy, . . .	1 doz.	With cradles and gimbals.
,, shadowless, .	2 ,,	With 500 lbs lampwick
,, scissors, . .	3	... ...
Lantern, dark, . .	2	Matches, 1 gross.
Oil-feeders, ...	½ doz.	... ...
Funnel, ...	1	... ...
Lamp-tray, ...	1	... ...
Turning-over machine for cable,	1	By Johnson & Phillips.
Speed indicators, .	2	... ...
Rotometers, . . .	2	... ...
Oil, boiled, ...	10 gallons,	... ...
,, mineral sperm, .	20 ,,	... ...
Turpentine, ...	5 ,,	... ...
Suet, ...	10 lbs.	... ...
Paints, ...	3 cwt.	Assorted.
Holms' lights, . . .	3 doz.	,,
Sounding machine, .	1	Sir Wm. Thomson's.
,, wire for machine,	6000 fms.	With winding frame and soda.
,, sinkers for machine,	1 doz.	Lucase's.
,, sinkers, .	1 ,,	Balls, iron.
Masthead balls, . .	3	... ...
Fitters' chest, complete, ...	1	... ...
Life-belts, ...	For every one	... ...

ELECTRO-CHEMICAL EQUIVALENTS.

From Electrician's Directory, 1885.

Calculated on the basis of Lord Rayleigh's recent determination of the electro-chemical equivalent of Silver, and the corrected atomic weights of the elements as given by Roscoe.

Elements.	Valency.*	Atomic Weight	Chemical Equivalent. e	Electro-Chemical (Grammes per Coulomb). z	Coulombs per Gramme q	Grammes per Ampere Hour. w	Log. q	Log. w
Electro-Positive.								
Hydrogen, ...	H^1	1·	1·	·000010384	96293·00	0 03738	4·9836353	$\bar{2}$·5727090
Potassium, ...	K^1	39·04	39·04	·00040539	2467·50	1 45950	3·3922572	0·1642041
Sodium, ...	Na^1	22·99	22·99	·00023873	4188·90	0·85942	3·6221000	$\bar{1}$·9342055
Aluminium, ...	Al^3	27·3	9·1	·00009449	1058·30	3·40180	3·0245939	0·5317086
Magnesium, ...	Mg^2	23·94	11·97	·00012430	804·03	4 47470	2·9055411	0·6507614
Gold, ...	Au^3	196·2	65·4	·00067911	1473·50	2·44480	3·1683501	0·3882433
Silver, ...	Ag^1	107·66	107·66	·00111800	894·41	4·02500	2·9515366	0·6047659
Copper (Cupric), . .	Cu^2	63·	31·5	·00032709	3058·60	1·17700	3·4855227	0·0707765
,, (Cuprous), . .	Cu^1	63·	63·	·00065419	1525·30	2·35500	3·1833553	0·3719909
Mercury (Mercuric), .	Hg^2	199·8	99·9	·00103740	963·99	3·73450	2·9840725	0·5722325
,, (Mercurous),	Hg^1	199·8	199 8	·00207470	481·99	7·46900	2·6830380	0 8732625
Tin (Stannic), . . .	Su^4	117·8	29·45	·00030581	3270·00	1·10090	3·5145478	0·0417479

* Valency is the number of hydrogen atoms it replaces. Atomic weight is the weight of the atom, taking hydrogen as 1.

ELECTRO-CHEMICAL EQUIVALENTS—*Continued.*

Elements.	Valency.	Atomic Weight	Chemical Equivalent. e	Electro-Chemical (Grammes per Coulomb). z	Coulombs per Gramme q	Grammes per Ampere Hour. w	Log. q	Log. w
Electro-Positive.								
Tin (Stannous), . . .	Su^2	117·8	58 9	00061162	1635 00	2·20180	3·2135178	0·3427779
Iron (Ferric), ...	Fe^4	55·9	18·64*	·00019356	5166·4	·69681	3·7131894	$\bar{1}$·8431131
„ (Ferrous), . . .	Fe^2	55·9	27 95	·00029035	3445·50	1·04480	3·5372523	0·0190332
Nickel, ...	Ni^2	58 6	29·3	·00030425	3286 80	1·09530	3·5167733	0·0395331
Zinc, ...	Zn^2	64·9	32·45	·00033696	2967·10	1·21330	3·4723322	0·0839682
Lead, ...	Pb^2	206·4	103·2	·00107160	933·26	3·85780	2·9700027	0·5863397
Electro-Negative.								
Oxygen, ...	O^2	15 96	7 98	·00008286	...	...	...	...
Chlorine, ...	Cl^1	35·37	35·37	·00036728	...	...	...	...
Iodine, ...	I^1	126·53	126·53	·00131390	...	...	...	...
Bromine, ...	Br^1	79·75	79·75	·00082812	...	...	...	...
Nitrogen, ...	N^3	14·01	4·67	·00004849	...	...	...	...

* Becquerel's extension of Faraday's law showed that the electro-chemical equivalent of an element is proportional to its chemical equivalent. The latter is equal to its combining weight, and not to atomic weight ÷ valency. For example, the ferric salt is an exception to the latter rule as are sesqui salts in general. The electro-chemical equivalent in grammes per C.G.S. unit, $Z = 10$ times z, because a coulomb $= \frac{1}{10}$ of the C.G.S. unit of quantity.

ELECTRO-CHEMISTRY.

Electrolysis.

Quantitative Laws of Electrolysis.—I. The amount of chemical action is equal at all points of a circuit.

II. The quantity of an ion liberated at an electrode in a given time, is proportional to the strength of the current.

III. The quantity of an ion liberated at an electrode in one second, is equal to the strength of the current in amperes multiplied by the "electro-chemical equivalent per coulomb" of the ion.

The above rules apply not only to the decomposition in a depositing bath, or outside the battery, but also to that taking place inside the charging battery itself.

One ampere decomposes ·00009324 gramme of water per second, liberating ·000010384 grm. of hydrogen, and ·00008286 grm. of oxygen.

The amount in grammes of any other ion liberated from an electrolyte in one second by a current of one ampere is given by the electro-chemical equivalent of the ion. The electro-chemical equivalent of any element is found by multiplying its chemical equivalent, or combining weight, by the equivalent for hydrogen—viz., ·000010384 (see Table pp. 329, 330).

If C = current in amperes, T = the time in seconds } C.T = Q = quantity in coulombs.
z = the electro-chemical equivalent (see Table, pp. 329, 330).
w = the weight in grammes of the ion (or element) liberated; then

$$w = \mathrm{C\,T}z = \mathrm{Q}z.$$

Weight of metal deposited from a solution of any of its salts by a current of C amperes in T seconds is

$$w = \mathrm{C\,T}z = \cdot 000010384\ \mathrm{C}a\ \mathrm{T}$$

where a is the chemical equivalent of the metal.

Example.—A current of ·5 amperes passes through a solution of cyanide of silver for ten minutes; weight of silver deposited—

$$w = \cdot 5 \times 10' \times 60'' \times \cdot 0011180 = \cdot 000010384 \times \cdot 5 \times 107\cdot 66 \times 10 \times 60 = \cdot 3354 \text{ grammes.}$$

Polarisation.—Whenever an electrolyte is decomposed by a current of electricity, the resolved ions have a tendency to reunite, thus setting up an opposing electro-motive force to the decomposing current. This tendency to reunite is commonly termed "chemical affinity." The electro-motive force of the decomposing current must therefore be greater than that due to the chemical affinity of the resolved ions. For example, when water is decomposed by a current of electricity into its constituent ions, oxygen and hydrogen, the opposing electro-motive force due to the chemical affinity of these two gases is about 1·5 volts; therefore, to decompose water, the battery should have an electro-motive force greater than 1·5 volts.

Electro-motive Force.—If Q = the quantity of electricity passed through an electrolyte in C.G.S. units,

E = the opposing electro-motive force in C.G.S units,

Z = the electro-chemical equivalent of the ion deposited per C.G.S. unit (see Table, pp. 329, 330).

H = heat of combination in gramme degrees of the ion in question with the other resolved ion (see Table, p. 334),

J = Joule's equivalent = 42×10^6,

The amount of work done

$$= EQ = QZHJ \text{ (Joules).}$$
$$\therefore E = ZHJ.$$

To express E in volts, divide by 10^8.

Or, the electro-motive force of any chemical reaction is equal to the product of the electro-chemical equivalent of the separated ion into the heat of combination expressed in fundamental units or ergs.

Example.—In decomposing water we can calculate the opposing E. M. F. that will be set up by the hydrogen tending to unite with the oxygen. By formula E=ZHJ (see Table, pp. 329, 330, for Z, and Table, p 334, for H and J), $\therefore$ E $= \cdot 00010384 \times 34000 \times 42 \times 10^6 = \cdot 00010384 \times 1\cdot 43 \times 10^{12} = 1\cdot 48 \times 10^8 =$ C.G.S. units of E.M.F. $\therefore \frac{E}{10^8} = 1\cdot 48$ volts. In the same way we may calculate the opposing E.M.F. set up in charging any secondary battery, or effecting any particular electrolysis. For Table of E.M.F., see pp. 357—9.

The principle and action of SECONDARY BATTERIES depend upon the above laws and rules.

Heat and Energy of Combination with Oxygen.

1 1 gramme of	2 Compound formed.	3 Calories or Gramme-degrees of heat produced = (H.)	4† Equivalent Energy in ergs = (H.J.)
Hydrogen, . .	H_2O	34000 A F	$1{\cdot}43 \times 10^{12}$
Carbon, . . .	CO_2	8000 A F	$3{\cdot}36 \times 10^{11}$
Sulphur, . . .	SO_2	2300 A F	$9{\cdot}66 \times 10^{10}$
Phosphorus, .	P_2O_5	5747 A	$2{\cdot}41 \times 10^{11}$
Zinc, . . .	ZnO	1301 A	$5{\cdot}46 \times 10^{10}$
Iron, . . .	Fe_3O_4	1576 A	$6{\cdot}62 \times 10^{10}$
Tin, ...	SnO_2	1233 A	5·18 ,,
Copper, . . .	CuO	602 A	2·53 ,,
Carbonic Oxide,	CO_2	2420 A	$1{\cdot}02 \times 10^{11}$
Marsh-gas, . .	CO_2 and H_2O	13100 A F	5·50 ,,
Olefiant Gas, .	,,	11900 A F	5·00 ,,
Alcohol, . . .	,,	6900 A F	2·90 ,,

Combustion in Chlorine.

Hydrogen, . .	HCl	23000 F T	$9{\cdot}66 \times 10^{11}$
Potassium, . .	KCl	2655 A	1·12 ,,
Zinc, ...	$ZnCl_2$	1529 A	$6{\cdot}42 \times 10^{10}$
Iron, ...	Fe_2Cl_6	1745 A	7·33 ,,
Tin, ...	$SnCl_4$	1079 A	4·53 ,,
Copper, . . .	$CuCl_2$	961 A	4·04 ,,

† Column 4 is obtained by multiplying the corresponding figures in column 3 by Joule's equivalent ($J = 42 \times 10^6$), since 1 gramme-degree of heat $= 42 \times 10^6$ ergs.

The authorities for these determinations are indicated by the initial letters A (Andrews), F (Favre and Silbermann), T (Thomsen). Where two initial letters are given, the number adopted is intermediate between those obtained by the two experimenters.

Electro-Metallurgy.

By J. T. Sprague.

Electro-metallurgy has two departments, which are distinguished by the preparation of the surfaces to be coated.

Electro-plating is the production of adhesive deposits, and depends on the absolute cleanness of the metal-surface coated.

Electro-typing is the production of removable deposits from either non-metallic moulds or from metal-surfaces, whose cleanness is destroyed either by black-leading or by rubbing with turpentine containing a trace of wax. The preparation of the objects depends (1) upon class of deposit required; (2) upon the nature of the object itself. In all cases, ordinary dirt, rust, &c., must be removed, as the deposit reproduces every feature of the surface, even to a finger mark.

Cleaning.—Copper, brass, zinc, and the noble metals are cleaned by the suitable acids which act on them. Such cleaning solutions may be prepared for different metals as follows:—

	Water.	Nitric.	Sulphuric.	Hydro-chloric.
For copper and brass, . .	100	50	100	2
Iron, . . .	100	2	8	2
,, (cast), .	100	3	12	3
Zinc, . . .	100	...	10	...
Silver, . .	100	10	...	...

It is best to make two such solutions; one being reserved for a final dip, during which a strong action occurs upon the surface. As this becomes weaker it can be used for the first cleansing, accompanied by occasional rubbing with sand, &c., according to the nature of the object.

Lead, tin, and pewter must not be placed in acid, but are cleaned by aid of caustic soda.

Objects must be carefully freed from acids if they are to be transferred to silver or gold solutions, but less care is necessary for objects cleaned in soda, nor is the same care necessary in transferring objects cleaned in acids to an acid coppering solution. In such cases the best plan is to dip into clean water, and at once transfer to the depositing cell.

Baths.—The solutions used to deposit from must be adapted to the object to be deposited upon, and must have no action, or but very little upon it, though cyanide of silver and gold have some chemical action upon copper and brass, which should be resisted by connecting the object to the electric circuit before immersion.

Suitable solutions can generally be made by passing a current from a plate of the required metal into a solution of the solvent, though it is

better to prepare them chemically. Thus, copper does not dissolve in dilute sulphuric acid, but it will dissolve and make a good working solution if the current is passed through a plate of copper. Silver solution may be thus prepared by using anodes of silver in a solution of 6 ounces of cyanide of potassium to the gallon of water; gold solution may be made with 2 to 3 ounces. A solution for depositing iron can be made in like manner with 1 part of sal-ammonias in 10 of water; so also may a nickel solution, but the best solution (the double sulphate) cannot be so made, because it is insoluble in excess of sulphate of ammonia. To prepare solutions in this manner large anodes should be used, and small cathodes which should be contained in a porous cell; the operation is complete when a deposit begins to form on the cathode.

Copper.—The best solution is a saturated solution of sulphate of copper, mixed with one quarter of water containing one-tenth its volume of oil of vitriol.

The rate of deposit varies with the nature and form of the surface, being greatest upon large, smooth surfaces, such as engraved plates; these may be deposited at the rate of 1 lb. per square foot per twenty-four hours, which is a current of 18 amperes per foot. Electrotype plates require slower working, because formed of a rough irregular surface, upon which sound metal cannot form so quickly as upon a smooth surface.

Non-metallic Surfaces, such as guttapercha, wax, &c., require great care at the first start to secure an even distribution of the metal coating, and the leading it into any hollows, which may

be done by temporary connections of fine wire coated with guttapercha except at the point, touching the surface at these parts, and causing the coating to start from their ends. The best black-lead should be used to give the conducting surface, thoroughly brushed into the surface. Gas carbon finely ground answers perfectly, but much of what is sold as black-lead is unfit for this purpose.

Natural Objects, such as flowers, leaves, ferns, insects, feathers, &c., give pretty effects when coated or coloured with different metals. They cannot be black-leaded or coated mechanically, and are prepared by dipping in solutions which can either penetrate them or form a perfect film of some material which will then reduce a thin film of silver or gold.

They may be soaked in an alcoholic solution of nitrate of silver, made by shaking 2 parts of the crystals in 100 of alcohol, with aid of heat, in a stoppered bottle; when dry the objects may be suspended under a shade and exposed to a stream of sulphuretted hydrogen.

Or immerse first in a solution of 1 part phosphorus in 15 parts bisulphide of carbon, 1 bees' wax, 1 spirits of turpentine, and 1 of asphaltum and one-eighth part of caoutchouc dissolved in bisulphide of carbon; this forms a thin adhering film over the surface, which is metallised by dipping in a solution of silver nitrate, about 20 grains to the pint of water.

Of course, the connecting wires should be attached before the dipping so as to ensure a perfect circuit between this wire and surface. By depositing silver and gold in different shades,

or colouring either silver or copper, very effective results are obtained. Oxidised silver surface is produced by washing with weak platinum chloride.

Coppering on Iron and other metals attacked by sulphate of copper is effected in an alkaline solution; a good solution, which can be worked cold, is made of $\frac{1}{4}$ oz. sulphate of copper to the pint required, dissolve in half a pint of water, add ammonia till all the first formed precipitate re-dissolves, forming a deep blue solution; then add cyanide of potassium till the blue colour disappears. A strong battery power giving off gas from the surface while depositing is required.

Weil's Solution consists of 150 parts Rochelle salt (tartrate of soda and potash) dissolved in 1000 of water, 80 parts of soda lime, containing 50 or 60 parts of caustic soda, and 35 parts copper sulphate are added. The lime removes the sulphuric acid, and a strongly alkaline solution results, in which the copper is held by the organic acid. As the metal is removed by the working, it is replaced by hanging muslin bags containing oxide of copper in the solution. Other metals, such as nickel, or alloys, as brass or bronze, may be deposited from a similar solution by substituting salts of them for the sulphate of copper.

Silver.—The only trust-worthy solution is the cyanide of silver dissolved in cyanide of potassium, which can be prepared as before described; it is best made by precipitation, as the other plan leaves carbonate of potash in solution. Nitrate of silver $3\frac{1}{2}$ ounces to the gallon of solution is dissolved in water, thrown down as a

white cyanide of silver by cyanide of potassium dissolved in water, carefully avoiding excess by sharp stirring, and trial of the clear liquid: this is washed and dissolved in as much more cyanide as was first used: about 2 ounces per gallon of the cyanide of potassium is also required to be maintained in the working. This gives a solution containing 2 ounces of silver per gallon, a good working strength. The silver plates used as anodes show the working state of the solution, as they should have a clear creamy colour; if they darken or turn pink, there is not sufficient free cyanide.

Britannia metal and other lead alloys work best with a larger proportion of free cyanide than is required for copper and its alloys. As the objects on first insertion act chemically on solution, special vessels should be used to produce the first deposit and solutions suited to different metals; then the general cell will be preserved from contamination.

Iron and Steel are usually coated first with a film of copper, as silver will not take on them.

Adhesion of the plating is rendered more perfect by amalgamating the objects before silvering and gilding; this is effected by dipping them in a solution of 1 ounce of nitrate of mercury in a gallon of water, which is well brushed over the object.

Solder requires careful cleaning and brushing with a camel-hair pencil (with an iron wire attached to it) dipped in weak solution of sulphate of copper, with which the iron sets up a galvanic circuit, causing deposit of copper on the solder surface.

Guttapercha is acted on by cyanide solutions, so it should not be used with them: they also dissolve wax and resin.

When it is desired to prevent deposit occurring on any part of the surface, it can be protected by copal varnish.

The objects themselves indicate the proper rate of working, which varies with temperature and strength of the solution. They should have a clear chalk-white colour and silky surface; if deposit is too rapid the colour will become yellow or gray.

Bright deposit is obtained by adding a little bisulphide of carbon, mixed with a strong solution of silver cyanide and free cyanide of potassium. It is only used to finish the coating, and can only be used on the large scale and in regular work, as this solution is very capricious and easily spoilt.

Cyanide of potassium should be purchased with a guaranteed percentage, as it varies very much in quality; it may only contain 45 per cent., and the white quality can only contain 80 per cent., while the black, if very well prepared, may contain 96 or 98.

Gold.—The best solution is the cyanide of gold in cyanide of potassium. It may be advantageously prepared by the current process, because of the risk of loss of metal in precipitation; but the chemical process gives the best result; using chloride of gold in place of nitrate of silver, the process is exactly the same as for silver solution.

This solution is worked hot, at about 150° Fah., and the result depends upon proper management

of the heat and current strength, and the articles should be kept in constant motion. The colour changes very rapidly, and the process can be mastered only by practice.

Green gold is produced by addition of cyanide of silver to the solution, or by working it from a silver anode till the desired tint is obtained.

Red gold is produced in the same way by addition of copper.

These solutions must be worked with anodes containing the proper metals, or by using double anodes of gold and the other metal, and controlling the action upon them.

The anode indicates the condition of the solution as with silver. They should be of a clear, dead yellow; if they become bright there is too much free cyanide, if foxy there is too little.

Nickel.—This metal deposits best from the double sulphate of nickel and ammonia; the double chloride also works well. The most essential point in the working is to keep the solution just neutral, or very slightly alkaline, by occasional addition of ammonia, which it loses during the action, and becomes acid when it does not work well. The solution should be kept at a specific gravity of 1·03, and worked with a low force, so that only a little hydrogen is given off from the objects. But the first production of the coating usually requires a larger force.

The anode surface should be greater than that of the objects to be deposited on.

Iron.—This can be deposited as a hard white film from the double chloride of iron and ammonia, which may be prepared by the current

process. It is used for coating engraved copper plates, which will then wear a great while, as the coating can be removed and renewed without injury, and will work with vermilion ink which injures copper.

Platinum.—This metal is deposited from several solutions, of which the best is the precipitate formed by soda or ammonia in platinic chloride dissolved in oxalic or citric acid.

The metal is always porous, and will not protect the metal beneath it against the action of acids.

Aluminium has been the subject of several patents, but does not appear to have been really deposited by any one.

THE ELECTRO-MOTIVE FORCES suited to the different metals are—

Copper in sulphate, . .	Volt, ·5 – 1·
,, cyanide, . .	4· – 6·
Silver in ,, . .	1· – 2·
Gold in ,, . .	·5 – 3·
Nickel in sulphate, . .	·5 – 1·

THE RESISTANCE will depend on the nature of the surface. Work is best effected with about equal surface of anode and objects, and the coating will be more even the greater the distance between them, especially where there are projecting points or rough surfaces.

THE CURRENT must be adjusted to the surface to be acted upon, and the proper limit is shown by the colour of the deposit, which deepens, while it tends to become granular as the current rises beyond the proper density.

Copper and *silver* should never show any sign

of hydrogen being given off at the objects; gold may show a few bubbles if deep colour is wanted. Nickel is always accompanied with evolution of hydrogen, but should not be allowed to froth.

THE RATE OF DEPOSIT is proportional to current, as described under the head of "Electrolysis," in the proportions given in the table of electro-chemical equivalents (except in the case of gold, the equivalent of which in combination with cyanogen is 197), but subject to modifications dependent upon the hydrogen action just described; there is also a partial solution of the metal, so that there is always a deduction to be made from the theoretical value. Thus—

Copper	give about	98	per cent.
Silver	,,	90 to 95	,,
Gold	,,	80 to 90	,,
Nickel	,,	80 to 95	,,

An ampere current maintained for one hour, which serves as a unit of quantity called the "ampere hour," represents

Gramme,	·038	Grain,	·568
Ounce Troy,	·00118	Ounce Avord.,	·00129

which multiplied by the chemical equivalent will furnish the weight of any substance deposited.

Current and Power Required to Deposit Copper.—(*Jamieson.*)

Example I.—To find the weight of copper, Cu, deposited in one hour from a solution of sulphate of copper, $CuSO_4$, by a current of one ampere.

$$w = C\,T\,z = 1 \times 60 \times 60 \times \cdot 000327 = 1\cdot 177 \text{ grammes.}$$

If w = increased weight of cathode in one hour in grains, then $C = w \div 18\cdot 35$ amperes. See p. 363 for consumpt. zinc.

Example II.—To find the current required to deposit one lb. of copper per hour from a solution of sulphate of copper.

Since one lb. = 453·58 grammes, and from example 1, one ampere deposits 1·177 grammes in one hour.

$$\therefore \quad \overset{\text{gms.}}{1{\cdot}177} : \overset{\text{gms.}}{453{\cdot}58} :: \overset{\text{ampere.}}{1} : x.$$

$$x = 385{\cdot}37 \text{ amperes.}$$

The E.M.F. necessary to deposit copper from a solution of sulphate of copper when both anode and kathode are of copper, is simply that required to overcome the resistance of the solution, for the copper at the anode in combining with the acid gives a + E.M.F. equal to about 1·26 volts, and in being deposited at the kathode the same as a — E.M.F.

Copper	$CuSo_4$	$CuSo_4$	$CuSo_4$	Copper
Anode	+ 1·26		−1·26	Kathode

Sprague in his second edition "Electricity," E. and F. Spon, p. 369, says—There is, however, a slight additional counter − E.M.F. of ·02 volt due to a concentration of the copper solution at the anode and impoverishment at the kathode plus a source of − E M.F. equal to the square root of the product of the current and resistance. He gives the full E.M.F. required as from "·5 to 1 volt," say ·8 volt in a well-regulated bath.

From Example II. and the above, we find the equivalent horse-power required to deposit 1 lb. of copper per hour

$$\text{H.P.} = \frac{E \times C}{746} = \frac{{\cdot}8 \times 385{\cdot}37}{746} = {\cdot}4 \textit{ roughly.}$$

A Siemen's C_6C dynamo run at 900 revolutions per minute, using four depositing cells in series takes ·85 indicated horse-power to deposit one lb. of copper per hour, or one horse-power deposits 1·1 lbs. of copper per hour. Larger machines are more effective, for a Siemen's C_1 will deposit about 5 cwt. in twenty-four hours, for 115 indicated horse-power, or say, two lbs. of copper per H. P. per hour, or ·5 H. P. per pound of copper deposited per hour, which is very economical. In the deposition of copper for the ordinary stereotyping of printed matter, four square feet go to the lb, of copper. so that for every horse-power-hour four square feet of strongly deposited copper can be secured by means of a good dynamo, and a well regulated depositing bath.

ANALYSIS and CHEMICAL EXAMINATION of the LEADING MATERIALS used by ELECTRICAL ENGINEERS. By ROBERT R. TATLOCK, F.R.S.E., F.I.C., F.C.S., Public Analyst for the City of Glasgow, Lecturer on Chemistry, College of Science and Arts, Glasgow, &c.

Iron Sulphate.—($FeSO_4 + 7H_2O$). Dissolve 4·92 grms. of pure, dry potassium bichromate in water, make up to 1 litre, and mix. Dissolve 2 grms. of the iron sulphate in 200 c.c. water, add 20 c.c. hydrochloric acid, then the bichromate solution from a burette till a drop of the mixture gives no blue or green colour when mixed with a drop of dilute solution of potassium ferricyanide on a white plate. The number of c.c. consumed multiplied by ·28 gives the percentage of iron. Pure iron sulphate contains 20·14, but is seldom obtained with more than 19·7 per cent. of metallic iron, the difference being chiefly due to excess of water.

Wrought Iron, Soft Steel, and Hard Steel.—The iron is estimated in these exactly as in iron sulphate, first dissolving 1 grm. in dilute hydrochloric acid with the aid of heat. The number of c.c. of potassium bichromate consumed is multiplied by ·56 to find the percentage of iron.

There is so little difference between wrought iron and soft steel that it is impossible to distinguish them by chemical means, but hard steel can be distinguished from these by the amount of carbon it contains. The proportion of that element can be determined as follows :—

Procure two test tubes having exactly the same internal diameter (about 1 cm.) and divided into tenths of cubic centimetres. In one tube place ·1 grm. of sample in fine borings, and in the other ·1 grm. of steel borings in which the percentage of carbon is known. To each add 3 c.c. nitric acid of sp. gr. 1·2, and heat in a water bath for half an hour. The samples are thus dissolved, and the solutions formed are of a brown colour, which varies in intensity according to the proportion of carbon present. Make up the standard with water so that each c.c. will represent ·1 per cent. of carbon (for example, if it contains ·5 per cent., make up to 5 c.c.), and dilute the solution of the sample till, on mixing and looking through tho mixtures horizontally, both solutions have the same depth of colour. Note the number of c.c. to which the sample has been made up, and multiply by ·1 to find the percentage of carbon. This process is not strictly accurate under all circumstances, as the intensity of colour varies to some extent, not only in proportion to the amount of carbon present, but also according to the treatment the steel has received during manufacture.

Wrought iron and the softest steel may contain as little as ·05 per cent. of carbon. Steel intended for boiler or ship plate contains from ·1 to ·2, for rails about ·4, for springs ·4 to ·6, and for cutlery sometimes as much as 1 per cent. of carbon.

Copper Sulphate.—($CuSO_4 + 5H_2O$). (1) Dissolve 20 grms. of potassium cyanide in water, and make up to half a litre with water. (2) Dissolve ·5 grms. of pure copper foil in 5 c.c.

nitric acid, dilute to 100 c.c., and add 20 c.c. of strong liquor ammonia, which will produce a deep blue colour. Add the potassium cyanide solution of (1), stirring well after each addition, till the blue colour is just discharged, or only a very faint violet remains. Note the number of c.c. consumed, and make the following calculation :—

c.c. of KCN consumed		1 c.c. of KCN		gram of Cu used
x	:	1	::	·5

The answer is the weight of copper, in grms., which 1 c.c. of the potassium cyanide is equal to. (3) Dissolve 2 grms. of the copper sulphate in 100 c.c. water, add 4 c.c. nitric acid and 20 c.c. ammonia (both having the same strength as those used at 2), then the potassium cyanide as before. To find the percentage of copper multiply the number of c.c. consumed by the amount of copper which each c.c. is equal to, and then multiply the answer by 50. Pure copper sulphate contains 25·45 per cent. of metallic copper.

Copper.—The percentage of real copper may be determined as in copper sulphate, but using only ·5 grams dissolved in 5 c.c. nitric acid.

To determine arsenic, dissolve 10 grams of the sample in nitric acid, evaporate off the excess of acid, add a little more nitric acid and some water, heat, and filter. Tin is thus removed. Make up the filtrate to a litre with water, render slightly alkaline with ammonia, add excess of ammonium sulphide, and allow to stand for 12 hours. Filter, and wash with weak

ammonium sulphide solution. Acidulate filtrate with hydrochloric acid, shake well, collect precipitate on a small filter, wash with water, pierce a hole in the filter, and wash the contents into a small flask with as little water as possible. Add 20 c.c. nitric acid, boil well, then add 10 c.c. hydrochloric acid, allow to stand in a warm place for a short time, filter (the filtrate should not exceed 120 c.c.), render slightly alkaline with ammonia, and add 20 c.c. excess of the latter. Now add 5 grms. pure ammonium chloride dissolved in a little water, and finally excess of magnesia mixture (prepared by dissolving 15 grms. pure crystallised magnesium chloride and 15 grms. pure ammonium chloride in 150 c.c. water, and adding 50 c.c. ammonia) while the liquor is still hot. Shake well and set aside for 12 hours. Collect the magnesium ammonium arsenate on a weighed filter, wash with dilute ammonia (1 part ammonia to 2 of water), dry at 100° C. and weigh. Multiply by 3·95 to find percentage of arsenic.

Copper usually contains traces of antimony, tin, iron, lead, and zinc, but the only impurity found to any extent is arsenic, of which high class samples of copper contain as little as ·02, while in lower class samples as much as 2 per cent. of arsenic may be found.

Zinc Sulphate ($ZnSO_4 + 7H_2O$). The principal impurities met with in zinc sulphate are the sulphates of lead and iron, but in a good sample there should not be more than traces of these. To estimate the quantity dissolve 2 grms. of the zinc sulphate in 250 c.c. water, add 10 c.c. hydrochloric acid, then pass sulphuretted hydro-

gen into the mixture, in which a black precipitate will be formed, if lead is present. Collect this on a filter, wash with water containing a little sulphuretted hydrogen, dry filter and contents, moisten them with a little nitric acid, and ignite in a porcelain capsule. To the residue add two or three drops sulphuric acid, ignite again, and weigh the sulphate of lead thus obtained. Multiply by 50 to bring to per cent. Boil down the filtrate from the lead to half its bulk, add 5 c.c. nitric acid, boil again, then add excess of ammonia. If iron is present a reddish brown precipitate is produced. Collect this on a filter, wash with dilute ammonia, dry, ignite, and weigh the ferric oxide. This result multiplied by 174 gives the percentage of crystallised iron sulphate ($FeSO_4 + 7H_2O$).

The proportion of zinc is determined in the filtrate from the iron as follows:—(1) Dissolve 4 grms. of caustic soda in half a litre of water, and saturate this solution with sulphuretted hydrogen gas, which thus produces sodium sulphide (NaHS). (2) Dissolve ·5 grams pure zinc in 10 c.c. hydrochloric acid, dilute to 200 c.c. with water, add excess of ammonia, then the sodium sulphide solution from a burette till, on allowing the zinc sulphide precipitate to settle, and mixing a drop of the clear liquid with a drop of very dilute cobalt chloride solution, a faint but distinct black colour is produced. Note the number of c.c. consumed, and make the following calculation:—

c.c. of NaHS consumed		1 c.c. of NaHS		grm. of Zn used
x	:	1	::	·5

The answer is the weight of zinc, in grms., which 1 c.c. of the sodium sulphide is equal to. The sodium sulphide can now be applied to the estimation of the zinc in the filtrate from the iron, the percentage being obtained by multiplying the number of c.c. consumed by the amount of zinc which 1 c.c. is equal to, and then by 50. Pure zinc sulphate contains 22·64 per cent. of zinc.

Zinc.—This metal, unless specially purified, seldom contains less than 1 per cent. of lead, with traces of iron, antimony, arsenic, and sometimes tin. The arsenic is determined as in copper. For tin and antimony dissolve 2 grms. in nitric acid, evaporate over a water-bath to dryness, add a few drops more of nitric acid and 100 c.c. water. If, after heating for a short time, a white precipitate remains, antimony, or antimony and tin will be present. Collect on a filter, wash with hot water, dry, ignite in a porcelain capsule, and weigh. The result multiplied by 39·6 will give the combined percentages of antimony and tin. The lead, iron, and zinc are determined in the filtrate from the antimony and tin as described under zinc sulphate, the lead sulphate being multiplied by 34, and the ferric oxide by 35, to find the percentages of lead and iron respectively.

Phosphor-Bronze.—This alloy differs from ordinary bronze in containing as much as ·2 per cent. and upwards, of phosphorus, in addition to the copper and tin. To determine the phosphorus, dissolve 2 grms. by heating with 30 c.c. of a mixture of equal volumes of nitric and hydrochloric acids, dilute with about 500 c.c.

water, pass excess of sulphuretted hydrogen through the solution, and render alkaline with ammonia. Allow to stand for an hour or two, add excess of hydrochloric acid, and again allow to stand, with occasional stirring, for an hour. The copper and the tin, and the lead and arsenic (if any), are thus precipitated. Filter, evaporate filtrate to 50 c.c. in bulk, add 10 c.c. nitric acid, boil, nearly neutralise with ammonia, and when at about 60° C. add excess of ammonium molybdate solution (prepared by dissolving 20 grms. ammonium molybdate in 25 c.c. water and 15 c.c. ammonia, and adding this cautiously, and with constant stirring, to a cooled mixture of 60 c.c. water and 60 c.c. nitric acid). Shake well, heat at about 50° C. for an hour, collect the yellow phospho-molybdate of ammonium precipitate on a weighed filter, wash three or four times with water containing one-twentieth of its bulk of nitric acid, dry filter and contents as well as possible by pressing between pieces of blotting paper, finish off the drying at 100° C., and weigh. Multiply the weight by ·326 to find percentage of phosphorus.

Determine the copper exactly as in copper sulphate, but first dissolving in nitric acid, and removing the tin by evaporation, &c. To estimate tin, dissolve 2 grms. in nitric acid, evaporate off excess of acid, add a few drops nitric acid and some water, heat, collect precipitate on a filter, wash with hot water, dry, ignite, and weigh. To find the percentage of tin, multiply by 39·6, and from the answer subtract the result obtained by multiplying the percentage

of phosphorus by 1·8. This result will also include the antimony, if present.

Mercury.—Heat a quantity of the sample in a porcelain capsule over a strong bunsen flame, till all the mercury is volatilised, taking care that the poisonous fumes are carried up a chimney. If any fixed residue remains, the mercury is not pure; but if not, it may be safely considered as pure.

Carbon.—Ignite 5 grms. of the carbon over a bunsen flame in a platinum capsule till all the black carbon is burned away. Weigh the ash, and multiply by 20 to find the percentage. Gas carbon used for Bunsen's cells should not contain more than 5 per cent. of ash.

Aluminium.—To find the proportion of pure aluminium, dissolve ·5 grm. in a mixture of hydrochloric and nitric acids, filter, precipitate alumina by ammonia, boil off excess of reagent, filter, and wash with hot water. Remove the precipitate from the filter, add hydrochloric acid, boil, reprecipitate with ammonia as before, collect on a filter, wash, dry, ignite, weigh. Multiply by 106·8 to find percentage of aluminium.

Aluminium Bronze.—This is an alloy of copper and aluminium. To determine the percentage of the latter, dissolve 2 grms. in nitrohydrochloric acid, dilute, precipitate copper by sulphuretted hydrogen, add excess of ammonia, and estimate aluminium as described above, multiplying result by 26·7. If zinc is present do not boil off excess of ammonia, although result will be slightly low. Zinc can be estimated in filtrate as in zinc sulphate; and copper, tin, and lead, as in phosphor bronze.

Silicium-Bronze. — The analysis of this alloy is made by precisely the same process as that described above for phosphor-bronze. An analysis of a sample of "Silicium-Bronze" Wire showed the following composition :—

	Per Cent.
Copper, ...	97·08
Tin, ...	2·81
Phosphorus, ...	·11
	100·m.

But it did not contain any silicon.

To test for silicon, dissolve 5 grams of the sample in nitric acid, evaporate gently to dryness, add a little nitric acid and some water to the residue, heat, collect the precipitate on a filter, wash, dry, and ignite it. Place the ignited precipitate in a porcelain boat, which transfer to a hard glass combustion tube, and attach the latter to an apparatus for generating and drying hydrogen. Heat the portion of the tube on which the porcelain boat rests to low redness, and pass the dry hydrogen gas through the tube till the whole of the tin oxide is reduced to the metallic state. Now allow to cool, place the contents of the porcelain boat in a beaker, add some strong hydrochloric acid, and boil for a few minutes. Collect the silica ($Si\ O_2$) which remains insoluble, on a filter, wash with hot water, dry, ignite, and weigh. Multiply the weight of the precipitate by 9·33 to find the percentage of silicon. It is advisable to repeat the reduction with hydrogen, &c., as described above, to make sure that all tin has been removed, and that the precipitate consists of pure silica.

Sulphuric Acid.—(1) The specific gravity should be taken, and should stand at least 1·84, or 168° Twaddell's hydrometer. To convert Twaddell's hydrometer degrees into specific gravity, multiply by 5, add 1,000, and cut off three places of decimals. Besides the strong acid there is a less pure weak acid made of specific gravity 1·72 (144° Twad.) (2) When diluted with three or four times its weight of water, it should *not* give a yellow precipitate (due to arsenic) when sulphuretted hydrogen gas is passed through the mixture. (3) When a little of the acid is heated gently over a Bunsen flame in a platinum capsule, until white fumes cease to be evolved, there should be only traces of residue left. (4) The acid should not contain nitrous compounds. These are best tested for by the nitrometer, which is first filled with mercury, then 5 c.c. water run in, and finally 10 c.c. of the sulphuric acid. The whole is then shaken up so as to bring globules of mercury in contact with the acid solution. The nitrous acid, &c., is decomposed, and nitric oxide gas is liberated. If only traces (say up to 0·1 or 0·2 c.c.) of nitric oxide are liberated, no notice may be taken of it, but if larger amounts are evolved it would be advisable not to use the acid.

Nitric Acid.—(1) The specific gravity of ordinary acid should be about 1·42, and that of the fuming acid 1·50. (2) On diluting with water, and adding barium chloride, no milkiness should be produced. (3) On diluting with water and adding silver nitrate, no white precipitate nor milkiness should result. (4) Little

or no residue should be left on evaporation of the strong acid over a low flame of an Argand burner.

Bichromate of Potash.—Commercial bichromate of potash is usually so pure that it is scarcely necessary to test it. However, it may be tested for sulphate of potash by dissolving in water, acidifying with hydrochloric acid, and adding barium chloride, when no white precipitate should appear. Chloride of potassium may be found by the addition of nitric acid and silver nitrate to a solution of the salt, when no white precipitate should be formed.

Cyanide of Potassium.—(1) Make up 13·08 grams pure silver nitrate crystals to 1 litre with distilled water. (2) Weigh out 1 gram of the cyanide of potassium, dissolve in 200 c.c. water, and add 1 gram of sodium hydrate. To this mixture add the silver nitrate solution from a burette till a faint but permanent white precipitate is formed. The number of c.c.'s consumed represents the percentage of cyanide of potassium in the sample.

Caustic Potash.—Dissolve 2 grams of the sample in 100 c.c. of water, add enough pure barium chloride solution to precipitate all the carbonates and sulphates, then colour pink by adding a few drops of alcoholic solution of phenol phthalein. To this mixture add normal sulphuric acid (1 c.c. = ·056 gram K H O) from a burette till the pink colour is just gone. Multiply the number of c.c. consumed by 2·8 to find the percentage of hydrates of potassium and sodium in terms of the former (caustic potash). The percentage obtained should not fall much

below 70. To ascertain whether the sample is really chiefly composed of caustic potash, and is not all soda, dissolve a fragment in water, acidify with hydrochloric acid, and add a little platinum tetrachloride, when a yellow precipitate should be produced.

Caustic Soda.—Test 2 grams exactly in the same way as caustic potash, but multiply the number of c.c. of normal acid consumed by 2. The result should show at least 70 per cent. caustic soda.

Binoxide of Manganese.—(1) Place 6 grams of iron sulphate (in which the percentage of iron has been determined as described in paragraph on *iron sulphate*), along with 1 gram of the binoxide of manganese, into a flask provided with a cork and exit tube. To this add 25 c.c. water and 25 c.c. strong hydrochloric acid, and boil till all black oxide of manganese is dissolved. Dilute with water, and estimate the iron still unoxidised. Subtract this from the total iron used, and calculate the remaining iron to percentage of binoxide of manganese, by multiplying by 77·6. Commercial samples contain from 60 to 70 per cent.

Sal Ammoniac.—Chloride of ammonium or sal ammoniac is usually fairly pure. (1) It should contain only traces, if any, of matter insoluble in water. (2) It should not leave more than a trace of residue when 5 grams are heated in a platinum capsule, over a low Bunsen flame, until white fumes cease to be evolved. (3) It should give little or no milkiness (showing presence of sulphate of ammonium) when dissolved in water, and hydrochloric acid and barium chloride added.

BATTERIES.

ARRANGEMENT OF CELLS.—*Single cell* gives

$$C = \frac{E}{r + R}$$

Where C = current in circuit.
E = electro-motive force of a cell.
r = internal resistance ,,
R = external resistance.

In series.—With a number of cells, n, connected "in series" (+ to − to + pole),

$$C = \frac{n\,E}{n\,r + R} = \frac{E}{r + \frac{R}{n}}$$

If R is very small compared with $n\,r$, $C = \frac{E}{r}$, or the current is that of a single cell.

If $n\,r$ is very small compared with R, $C = \frac{n\,E}{R}$, or the current increases as the number of cells.

The last condition pertains to telegraph work; the former to electric lighting. The value of r is nearly inversely proportional to the area of the plates when fronting each other in the liquid, and as their distance apart. Hence, if the area of the plates is increased n times;

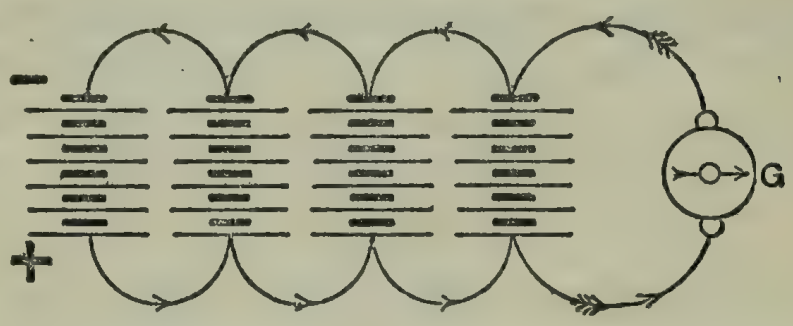
$$C = \frac{E}{\frac{r}{n} + R} = \frac{n\,E}{r + n\,R}.$$

This is the case when one large "quantity" cell is formed out of n small ones by connecting their like poles together. If n R is very small,

$$C = \frac{nE}{r}.$$

For continuous work small cells are soon exhausted.

Grouping of Cells and Batteries.—Batteries or sets of cells in "series" may sometimes be advantageously arranged for what is popularly termed "quantity" in order to produce a strong current through a small resistance, by joining up the separate batteries or sets of cells in "parallel" or multiple arc; thus—



The above figure represents four batteries or sets of cells with six cells in each battery or set, joined in parallel or multiple with a galvanometer, G.

(1.) The *Internal Resistance* of the whole battery is now obviously equal to the joint resistance of the four separate batteries.

Let N = the total number of cells in whole battery.
r = the internal resistance of each cell.

n_s = the number of cells in each set or series.
n_q = the number of batteries or sets in parallel or quantity.
R = the external resistance as before.
E = the E.M.F. of each cell.
C = the current flowing in the circuit.

Then,

The *internal resistance* of the whole

$$= \frac{n_s \times r}{n_q}.$$

For Example.—Suppose we take the case of the last figure and let $r = 10$ ohms; $n_s = 6$ cells; $n_q = 4$ sets. Then the internal resistance of the whole battery

$$= \frac{n_s \times r}{n_q} = \frac{6 \times 10}{4} = \frac{60}{4} = 15 \text{ ohms.}$$

(2.) *To find the best arrangement of a given number of cells* (N) *to obtain a maximum current* (C) *working through an external resistance* (R).

For the current to be a maximum the cells must be arranged so that the internal resistance of the whole battery is as nearly as possible equal to the external resistance, or;

$$\frac{n_s \times r}{n_q} = \text{R}.$$

But in any circuit,

$$\text{The current} = \frac{\text{Total E.M.F.}}{\text{Total Resistance}}.$$

$$\therefore\ C = \frac{n_s E}{\frac{n_s r}{n_q} + R} = \frac{n_q n_s E}{n_s r + n_q R}.$$

Again, since $N = n_s \times n_q$, $\therefore\ n_s = \frac{N}{n_q}$ and $n_q = \frac{N}{n_s}$. Now substitute the above value for, n_q, in equation $\frac{n_s r}{n_q} = R$.

And we have $\frac{n_s r}{\frac{N}{n_s}} = R = \frac{n_s^2 r}{N}$.

Or the number of cells in series, $n_s = \sqrt{\frac{N R}{r}}$.

And in precisely the same way, by substituting in the same equation the value for n_s previously obtained, we get

The number of sets in parallel, $n_q = \sqrt{\frac{N r}{R}}$.

For Example.—Adopting the same numerical values as before,

$$n_s = \sqrt{\frac{N R}{r}} = \sqrt{\frac{24 \times 15}{10}} = \sqrt{36} = 6 \text{ cells,}$$

and

$$n_q = \sqrt{\frac{N r}{R}} = \sqrt{\frac{24 \times 10}{15}} = \sqrt{16} = 4 \text{ sets.}$$

(3.) *To find the greatest current which can be obtained from a given number of cells* (N) *through a given external resistance* (R).

Taking the equation for C, found from (2), also substituting the value, also found under (2), for n_s, and letting the internal resistance of the battery equal the external, we have

$$C = \frac{n_s E}{\frac{n_s r}{n_q} + R} = \frac{E\sqrt{\frac{N R}{r}}}{2 R} = \frac{E}{2}\sqrt{\frac{N}{R r}}.$$

For Example.—Adopting the same numerical values as before,

$$C = \frac{1}{2}\sqrt{\frac{24}{15 \times 10}} = \frac{1}{2}\sqrt{\cdot 16} = \cdot 2 \text{ ampere.}$$

(4.) *To find the number of cells in series* (n_s) *and in parallel* (n_q) *required to give a current* (C) *through an external resistance* (R) *and to have an efficiency* (F).

$$\text{The efficiency } F = \frac{\text{External work}}{\text{Total work}}$$

$$= \frac{C^2 R}{C^2\left(\frac{n_s r}{n_q} + R\right)} = \frac{R}{\frac{n_s r}{n_q} + R}.$$

Or, the internal resistance of whole battery,

$$\frac{n_s r}{n_q} = \frac{R(1 - F)}{F},$$

$\therefore$ substituting this value in equation,

$$C = \frac{n_s E}{\frac{n_s r}{n_q} + R}, \text{ we have } C = \frac{n_s E F}{R},$$

$$\therefore\ n_s = \frac{C R}{E F} \text{ and } n_q = \frac{C r}{E(1 - F)}.$$

There are always two values for the efficiency (F) for any particular number of cells (N).

$$\text{For, } N = n_s \times n_q = \frac{C R}{E F} \times \frac{C r}{E(1 - F)} = \frac{C^2 R r}{E^2 F(1 - F)},$$

$$\text{Or,} \qquad F = \frac{E\sqrt{N} \pm \sqrt{N E^2 - 4 C^2 R r}}{2 E \sqrt{N}},$$

which gives two values for (F) except when

$$N E^2 = 4 C^2 R r.$$

That is, when the rate of working is a maximum or when the efficiency is 50 per cent.

For Example.—Taking the same numerical values as found before and in the last figure—viz., N = 24 cells; E = 1 volt; C = ·2 ampere; R = 15 ohms; r = 10 ohms;

$$\text{Then,} \qquad N E^2 = 4 C^2 R r$$
$$24 \times 1^2 = 4 \times \cdot 2^2 \times 15 \times 10$$
$$24 = 24.$$

And,

$$F = \frac{E\sqrt{N}}{2 E \sqrt{N}} = \frac{1}{2} = 50 \text{ per cent.}$$

Electro-Motive Forces of Various Cells.

	+ Plate.	Porous Cell.		— Plate.	B.A. Volts.
Daniell,	Zinc amalg.	Sulphuric acid, 7½ to 1	Saturated solution of copper sulphate	Copper	1·079
,,	,,	22 to 1	,,	,,	0·978
,,	,,	,,	Nitrate of copper saturated	,,	1·000
,,	,,	,,	Sulphate of copper	,,	0·909
,, P. O. Standard,	,,	Sulphate of zinc saturated solution	,, ,, Saturated solution	,, ,,	1·07 1·079
Grove,	,,	Sulphuric acid, 7½ to 1	Nitric acid (fuming)	Platinum	1·956
,,	,,	Salt water	Nitric acid, sp. gr. 1·33	,,	1·904
,,	,,	Sulphuric acid, 22 to 1	,,	,,	1·810
,,	,,	Sulphate of zinc	,,	,,	1·672
Bunsen,	,,	Dilute sulphuric acid	Nitric acid	Carbon	1·734
Smee,	Zinc	Sulphuric 1, water 7		Platinised sil.	·48..1·1
Walker,	,,	,,	,,	,, carbon	·5..1

Note.—These E.M.F.'s are 1·1 per cent. too high, and should be multiplied by ·9889, the ratio of the B.A. unit to the legal ohm. (See p. 14.)

ELECTRO-MOTIVE FORCES OF VARIOUS CELLS—*Continued.*

	+ Plate.	Porous Cell.		– Plate.	B.A. Volts.
Callan,	Zinc amalg.	Dilute sulphuric acid	Nitric acid	Cast iron	1·700
Poggendorf,	,,	,,	Bichromate of potash	Carbon	1·796 2·028
Marié Davy,	,,	Sulphuric acid, 22 to 1	Paste of sulphate of mercury	,,	1·524
,,	,,	Dilute sulphuric acid	,,	,,	1·33
Leclanché,	,,	Solution of sal ammoniac	Binoxide of manganese	,,	1·48
Dela Rue (p. 334)	Zinc	Chloride of ammonium		Silver, + AgCl	1·030
Skrivanov,*	,,	Solution 75 caustic potash to 100 water		,, ,,	1·4 to 1·5
Schanschieff,	,,	,, of basic sulphate of mercury		Carbon	1·39
Becquerel,	Zinc amalg.	Sulphate of Zinc	Sulphate of lead	Lead	0·55
Niaudet,	,,	Common salt	Chloride of lime	Carbon	1·65
Duchemin,	,,	,,	Perchloride of iron	Lead	1·541
,, Secy. Battery,	Platinum	Dilute sulphuric acid	Dilute sulphuric acid	Platinum	1·79
Latimer Clark (standard cell)	Zinc amalg.	Sulphate of Zinc	Paste of sulphate of mercury	Mercury	1·45

Note.—These E.M.F.'s are 1·1 per cent. too high, and should be multiplied by ·9889, the ratio of the B.A. unit to the legal ohm. (See p. 14.)

* Used for electric "star" lights.

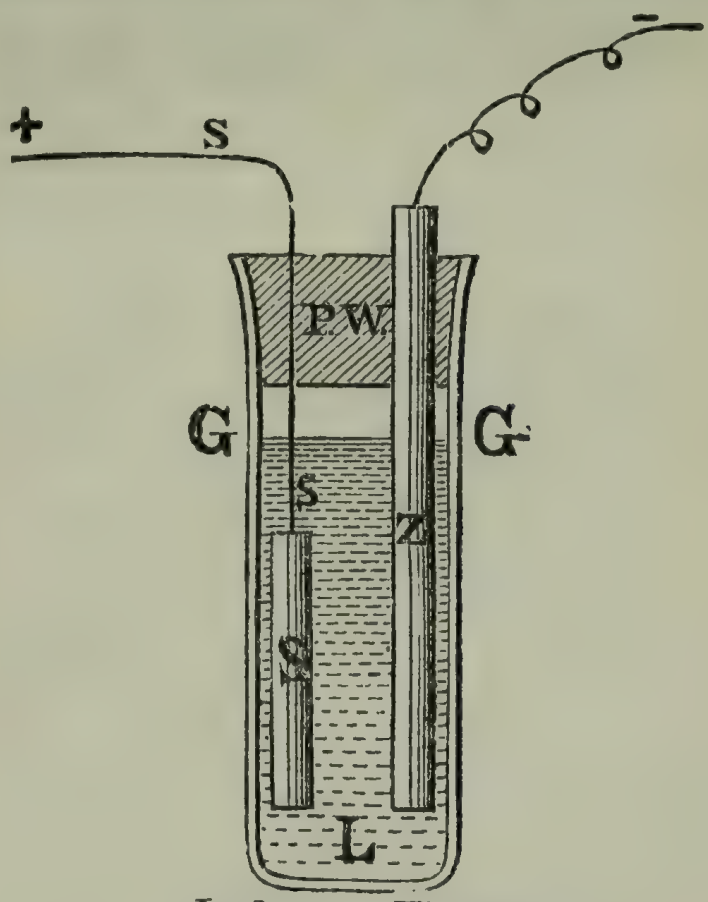
ELECTRO-MOTIVE FORCES OF VARIOUS CELLS—*Continued.*

	+ Plate.	Porous Cell.		— Plate.	B.A. Volts.
Howell's manganese; internal res. = 1 ohm (*Hockin*),	Zinc amalg.	Ammonic sulphate, 25 grammes crystallised salt to 1 litre water	Sulphuric acid, 1 acid to 5 parts water	Carbon + manganese dioxide + manganese sulphate	2·04
Higgin's cascade, internal res. = ·170 ohm,	Zinc in mercury	Chromic acid	Sulphuric acid	Carbon	1 9
Thame's,	Zinc	Dilute sul. acid	Nitric acid + CrO_2Cl_2	Carbon.	2
Bennet's, internal res. = 5 ohms,	,,	Potassium hydroxide (KHO), with distilled water	Damped with (KHO) and water	Iron can with iron borings	1·3
Lalande - Chaperon,	Zinc amalg.	Caustic soda solution	Oxide of copper or "copper scale"	Iron	1
Faure's secondary battery (see p. 334 *b*),	Lead plate coated with minium	Dilute sulphuric acid	Dilute sulphuric acid	Lead plate coated with minium	2· to 2·2
Sellon-Volckmar,	Lead plate primed with minium	Sol. sulphuric acid, sp. gr. 1,100°	Sol. sulphuric acid, sp. gr. 1,100°	Lead plate primed with minium	2 15
Planté,	Lead	Dilute sul. acid	Dilute sul. acid	Lead (spongy)	2· to 2·2

Note.—These E.M.F.'s are 1·1 per cent. too high, and should be multiplied by ·9889, the ratio of the B.A unit to the legal ohm. (See p. 14.)

Standard Cells.

Chloride of silver, or, De la Rue's element.



Index to Figure.

G G = Glass vessel closed by
P W = Stopper of paraffin wax.
Z = Zinc or positive element, consisting of a cylindrical rod of chemically pure zinc.
S = Chloride of silver cylinder, or negative element, surrounded by parchment paper to prevent contact with Z.
s = Fine silver electrode cast into S.
L = Liquid solution of chloride of ammonium, 403 grains to 1 quart water, or 1 part in 40.

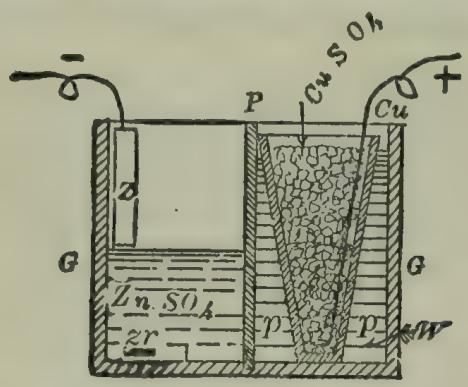
The internal resistance of a cell 6″ high, 1″ diameter, with zinc $\frac{3}{16}$″ diameter, is 3 to 4 ohms, but increases on standing by adhesion of zinc oxychloride to the zinc. Frequent use or scraping the rod keeps the resistance normal. Hermetical sealing retards the formation of oxychloride. About 15 minutes of short circuiting is required to bring out the full current of a new battery, and a few seconds that of one at rest. It is well adapted for testing and signalling in cable work, especially at sea.

Clark's element should be made by the user, as it deteriorates with shaking, and requires great care in making and moving it. Dissolve pure zinc sulphate to saturation in boiling distilled water. When cool, pour the solution from the crystals and mix to a thick paste with pure mercurous sulphate. Boil the paste to drive out any air, then pour it on the surface of a small quantity of pure mercury previously heated in a suitable glass cell. Suspend a piece of pure zinc in the paste, and seal the vessel up with melted paraffin wax. Contact with the mercury is made by a platinum wire passing down a glass tube, blown on the outside of the cell, near the bottom, and opening into the mercury. Contact with the zinc is made by a copper wire soldered to it. Mercurous sulphate can be bought, but may be prepared by dissolving pure mercury in excess in hot sulphuric acid at a temperature below boiling point. The salt should be well washed in distilled water, and care taken to get it free from mercuric sulphate (persulphate), the presence of which is shown by the mixture turning yellow on the addition of water. Unless these precautions are taken, the E.M.F., which is 1·435 true volt at 15·5° C., may be affected. For a range of 10° above or below this temperature, the E.M.F. rises or falls ·08 °/₀ per 1° C.

Standard Daniell elements.—The simplest is Sir W. Thomson's tray form, made of a square dish of sheet copper, 6″ × 6″ × 1½″ deep, into which is fixed, at ¾″ from the bottom, a flat zinc plate, having ½″ clear between it and the copper. Sulphate of zinc solution (specific gravity, 1·02)

is poured into the dish, then a definite quantity of a saturated solution of sulphate of copper is gently poured in, sufficient to raise the sulphate solution over the zinc. The cell is short circuited a few minutes to deposit pure copper on the dish. When carefully made, the E.M.F. is from 1·072 to 1·075 volts.

POST-OFFICE PATTERN STANDARD CELL.



Where	*G*	represents	Glass vessel divided into two compartments by
,,	*P*	,,	Partition (glass).
,,	*Z*	,,	Zinc plate, pure and well-amalgamated, almost reaching to
,,	*Zn SO4*	,,	Saturated solution of sulphate of zinc.
,,	*zr*	,,	Zinc rod, which takes up any copper from solution percolating through
,,	*pp*	,,	Porous pot removed into zinc compartment when in use, and containing
,,	*Cu*	,,	Copper strip in a solution of
,,	*Cu SO4*	,,	Sulphate of copper with crystals.
,,	*W*	,,	Water.

Method of Using.—When required for testing purposes, the porous pot, *pp*, containing copper plate, &c., is removed from *W*, water compartment, and inserted into $Zn\ SO_4$. This forms an excellent standard cell—its E.M.F. = 1·07 volts, and is very constant.

In a newer form *pp* contains *z* in $Zn\ SO_4$, and is lifted from its own compartment into the other containing *Cu* in $Cu\ SO_4$.

Bichromate solutions.—4 oz. bichromate of potash, saturate 1 pint of boiling water. The sulphuric acid should be added cold, 1 in 20. *Tissandier's* solution for electric light batteries is, water 100, bichromate 16, sulphuric acid (at 66°) 37 parts. The bichromate is powdered fine, care being taken not to breathe the dust. It is dissolved in the water at 40° C., and the acid gradually added while shaking the whole. Use when the temperature falls to 35°; at a temperature below 15° C. the liquid works badly. *Chutaux's* circulating solution is composed of, water 150, bichromate 10, bisulphate of mercury 10, sulphuric acid (at 66°) 5 parts.

Amalgamating zinc.—Immerse the zinc in dilute sulphuric or hydrochloric acid for a few minutes to give it a clean surface, then rub the mercury on with a hard brush or cloth fixed on the end of a piece of wood, not with bare fingers, as it is dangerous.

Porous pots.—The Post-Office test is to put the pot in a standard cell and observe the current. The French test is to fill it with distilled water at 14° C.; the minimum leakage is 15 per cent. in 24 hours.

Consumption of zinc in a battery.—

Let w = weight of zinc consumed per cell.

C = current produced in amperes.

T = Time in seconds; n = number of cells.

z = Electro-chemical equivalent for zinc = ·00033696. (See p. 330).

Then $w = \mathrm{C\,T}\,z$.

$= \mathrm{C} \times \cdot 000337$ grammes per second.

$= \mathrm{C} \times 1\cdot 213$,, ,, hour.

$$\mathrm{W} = n\,w = \frac{\mathrm{C}\,n \times 1\cdot 213}{453\cdot 59} \text{ lbs. per hour.}$$

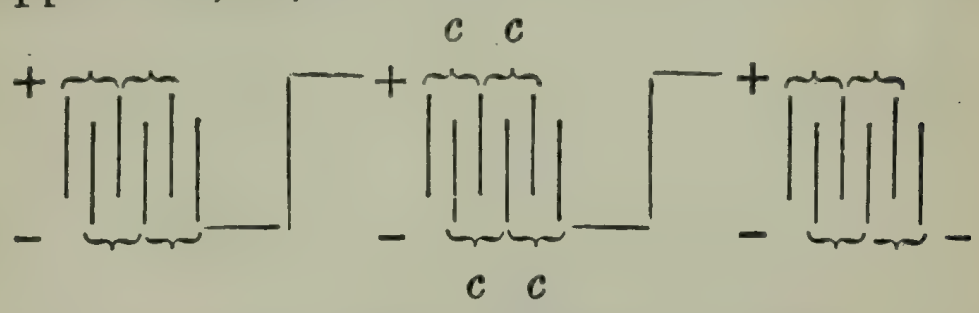
An electric horse-power an hour requires the consumption of $\frac{2}{E}$ lbs. of zinc, where E = E.M.F. of one cell in volts;

$$\therefore W = \frac{\text{H.P. per hour} \times 2}{E} \text{ in lbs.}$$

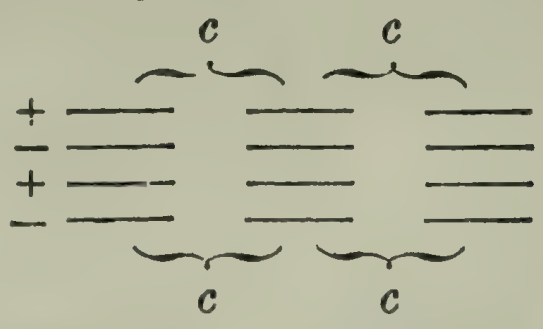
Accumulators or Secondary Batteries.

Arrangement of cells to give a certain electromotive force and internal resistance.

Example.—To get an E.M.F. of 3 cells and resistance of 1 cell from 9 cells, connect with copper bars, *c c*, thus:—



By Dr. Muirhead's method, requiring fewer bars, connect thus:—



Planté's accumulator.—Reduced lead, peroxide of lead, and sulphuric acidulated water. E.M.F. in charging, at least 1·95, in discharging, at most 1·85 volts. Therefore, the coefficient of fall = 0·95 (*Reynier*). Planté, Gladstone, and others, find the E.M.F. 2 volts.

Copper accumulator.—Lead, copper, lead peroxide, acid solution of sulphate of copper. E.M.F. in charging, at least 1·43, in discharging, at most 1·25 volts. Coefficient of fall = 0·87.

Amalgamated zinc accumulator.—Zinced lead, lead peroxide, acid solution of sulphate of zinc. E.M.F. in charging, at least 2·4 volts, in discharging, at most 2·36 volts. Coefficient of fall = 0·983—*Reynier.*

In practice the fall would be a little more.

G. Faure's accumulator.—A single Faure cell consists of two clean lead plates, each plate being coated with a paste, made by mixing minium (Pb_3O_4) with dilute sulphuric acid (H_2SO_4). The coated plates are then covered with felt cloth, bound or rolled up together, and immersed in a trough containing dilute sulphuric acid. The following chemical reaction takes place at *both* plates between the minium and sulphuric acid, *before* the application of any charging current. $Pb_3O_4 + 2\,H_2SO_4 = PbO_2 + 2\,PbSO_4 + 2\,H_2O$. The Faure cell is now charged with a current (from a separate battery or dynamo), with an E.M.F. not exceeding 3 volts, when more peroxide of lead, PbO_2, is formed at the positive lead plate, as well as sulphuric acid; thus, $PbSO_4 + H_2O + O = PbO_2 + H_2SO_4$. At the negative plate, the PbO_2 and $2\,PbSO_4$ are both reduced to spongy or porous metallic lead, with formation of sulphuric acid and water. Consequently, sulphuric acid is generated during charging at both plates, so that the strength of the solution is fully kept up. When the minium has been fully converted by a number of successive charges and discharges,

we have, on again charging the cell, a layer of peroxide of lead adhering to one lead sheet, forming a + plate, and a layer of spongy lead adhering to the other, forming a − plate, with a difference of potential between them = 2 to 2·2 volts. The resistance between the plates being very small, a strong current is produced on joining them through a small external resistance, and 80 per cent. of the energy of the last charge can be obtained in the discharge with newly-formed cells, but with continued use and age the percentage return decreases. — *Gladstone and Tribe.*

Efficiency of accumulators.—In charging an accumulator by a dynamo, the total Watts spent in the circuit are

$$E\,C = E_1\,C + (D.P.)\,C + C^2\,R.$$

Where E = total electro-motive force of the generator : C = strength of current.

E_1 = electro-motive force of the accumulator disconnected.

(D.P.) = difference of potential between the poles of accumulator when charging.

R = resistance of generator and connecting wires.

$E_1\,C$ = the total Watts spent in the battery.

(D.P.) C = waste-heat generated in battery, in Watts.

$C^2\,R$ = waste-heat generated in generator and leads.

Hence $\frac{E_1\,C}{E\,C} = \frac{E_1}{E}$ is the efficiency.

∴ To get a high efficiency, as many cells should be in circuit so as to give E_1 nearly equal

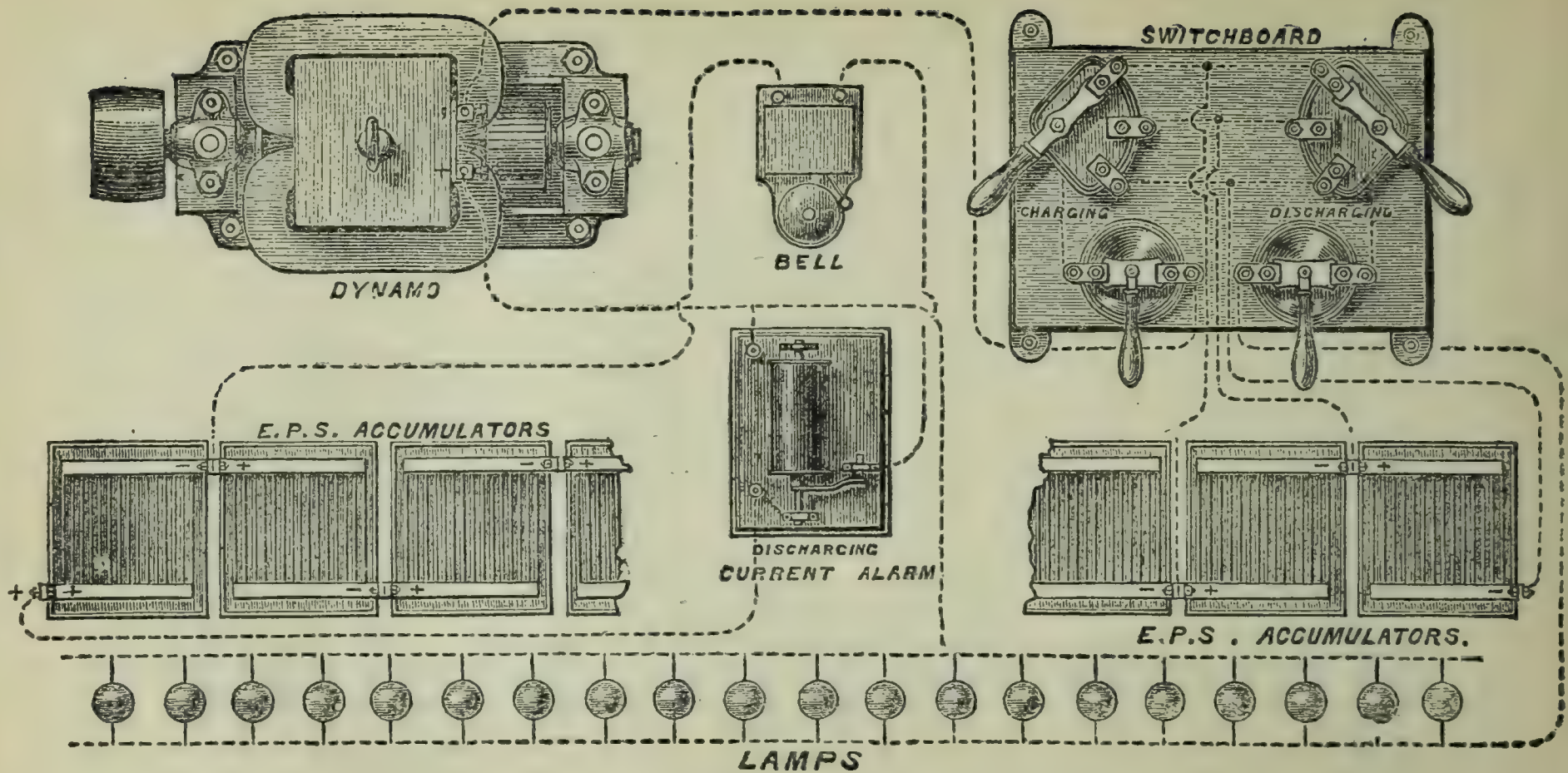
to E, that is, the charging should be as slow as the machinery will permit. The efficiency is also increased by increasing E and E_1, while keeping $E - E_1$ constant. If E is increased to nE, and E_1 to E_2, while $nE - E_2 = E - E_1$, the electrical efficiency is $\frac{n-1}{n} + \frac{1}{n} \times \frac{E_1}{E}$.

Faure-Sellon-Volckmar or E.P.S. Accumulators.—The lead oxide in the form of paste is pressed into the perforations of cast metallic grids, consisting principally of lead. When dry, the plates are inserted side by side in troughs containing dilute sulphuric acid, and are alternately connected to the positive and negative poles of a dynamo. On the passage of the current, the plates joined to the, +, are converted into peroxide of lead, the others at the same time being reduced to pure spongy lead. When this process or formation is complete, the plates are arranged into sections of alternate positive ($Pb\,O_2$) and negative (Pb), suitable insulators of india-rubber or other material separating them from one another. The projecting lugs are then burnt on to stout leaden strips which form the positive and negative terminals of the cell—the + terminal is painted red, and the, —, black. Any number of plates between 7 and 31 may be thus connected to form one cell. Several types of plates are manufactured to suit various purposes; the "L" being invariably manufactured for ordinary lighting purposes. For traction and other cells see special lists.

	L
Approximate dimensions, . .	$9\frac{1}{2}'' \times 9\frac{1}{2}'' \times \frac{3}{16}''$;
Mean weight of, +, &, — plates,	5 lbs. 3 oz.;
Total discharge per positive plate	50 amp. hrs.;
Safe rate of discharge per positive plate, . .	4·3 amperes.

For lighting and other purposes, where the cells are placed in a permanent position, glass containing vessels are to be preferred, in other instances teak lead-lined boxes with or without lids are used. In the case of using accumulators on board steamers, water-tight lids are fitted.

The connections in accumulator installations should be made as shown in sketch. As will be seen, the last or regulating cells may be at will placed in or cut out of both charge and discharge circuits. It is desirable to connect the switches and ammeter in such a manner, as to facilitate the measurement of the current passing in or out of the battery at any time. The cells may be placed on strong wooden stands, one or more tiers high, dependent upon the space at disposal. They should not work in the vicinity of the engine or any other bright machinery, owing to the action of the sulphuric acid spray which is carried into the atmosphere during charge. In case a separate room or cellar cannot be appropriated to them, the stands may be enclosed in a cupboard. It is necessary that every cell should be accessible for inspection; at any rate, from one side. The use of a separate wooden



PLAN OF GENERAL ARRANGEMENT.

tray for each cell supported by insulators containing a suitable non-evaporating oil, will greatly improve the efficiency of the battery, and at the same time prolong its life. It must be remembered that the durability of a storage cell depends almost entirely upon the course of treatment to which it is subjected. The necessary precautions can, however, be observed in any installation without exertion or difficulty. The main points to be attended to are:—

1*st*. The dilute sulphuric acid 1170 specific gravity, Twaddle, must not be put into the cells until the charging plant has been tested, and proved capable of running for 36 hours without cessation, as it is necessary that the cells should be thoroughly and fully charged without delay after the addition of the solution, to avoid the formation of lead sulphate, and consequently the immediate destruction of the plates.

2*nd*. The rates of charge and discharge should not exceed the safe limits specified.

3*rd*. The plates must never be exhausted; it is preferable to withdraw only three-fourths of the total capacity.

4*th*. The cells must not rest uncharged or only partially so. If it is desired to leave the battery idle for say two or three months, the acid must not be removed nor the plates from the cells, but a thorough charge should be given until the peroxide plates assume a deep chocolate colour and gas is violently evolved, after which there will be but little fear of sulphating setting in.

To determine the number of cells required to form the battery in any installation, the E.M.F. of the lamps must be divided by 2, and two cells added to the total thus found if 50 or 60 volt, and 3 in the case of 100 volt installations.

Instructions for Fixing E.P.S. Accumulators.

The cells should be carefully unpacked, and any straw or dust removed from between the plates, which can be easily effected with bellows.

The wooden bottom blocks should be carefully fitted to the shape of the bottom of glass cell and should then be placed inside each box with the narrow edge uppermost.

The cells should be arranged on strong wooden shelves protected with shellac varnish; when in tiers a space of not less than 22 inches should be allowed between the shelves. When trays and insulators are used 30 inches should be allowed.

Where glass boxes are used, they should stand on dry sawdust retained by a narrow ledge, or preferably on separate trays containing sawdust and supported on glass fluid insulators.

The cells should be placed with the edges of the plates to view, and should only be arranged in double rows when they are accessible from the back.

A space of about an inch should be left between each cell, or half an inch between each tray.

The acid must not on any account be put in till all is ready for charging.

The brown plates (called *positives*, *i.e.*, those connected with the positive pole) are smaller than the grey plates (called *negatives*, *i.e.*, those connected to the negative pole). Great care should be taken in putting them into the boxes. The *negatives* should project equally on each side, in order that the *positives* may be firmly held by all the rubber plugs or bands.

It will be seen from the plan that the (+) positive, coloured red, is connected to the (−) negative, of the next cell throughout the battery.

Thus there will be a disconnected positive lug at one end, and a negative at the other end of the battery. These are the accumulator terminals which are connected to the dynamo with the positive of the accumulator to the positive of the dynamo, and negative to negative.

Cells should not be connected in parallel; but wherever the capacity of the largest cells is insufficient, they should be formed into two batteries, and the batteries connected in parallel by coupling the ends. This course having the additional advantage of allowing repairs or alterations without interruption of the current. Arrangements should be made to allow of the current from or to each battery being tested without interruption of the circuit.

The dynamo before being connected should be tested for polarity, which may be done as follows:—Place two clean strips of sheet lead in a stone jar filled with dilute acid; separate them with a block of wood, and connect one to a terminal of the dynamo, connect the other to one terminal of an incandescent lamp, and the other lamp terminal to the other terminal of the dynamo. After the dynamo has been running for a few minutes, one of the lead strips will become brown, showing that the terminal connected to this strip is the positive, which must be connected to the positive of accumulators.

The contact surfaces of the lead lugs must be scraped clean, and the connecting bolts firmly screwed up, after which the ends of the lugs above the bolt may be carefully soldered or burned together.

The dynamo used for charging should be either shunt wound, or separately excited, and the electro-motive force should be specified in order-

ing the dynamo, as 2·5 volts for each cell to be charged.

When everything is ready for charging, and the dynamo has been tested for polarity, the acid solution is put into the cells to a height of not less than ½ in. above the negative plates.

The sulphuric acid must be free from impurities, such as arsenic, nitric or hydrochloric acid, and must be diluted with pure water to a specific gravity of 1170, as shown by the hydrometer.

If the solution is not obtained from the Company ready for use, the acid must be mixed with water in a separate vessel, well stirred and allowed to cool before the specific gravity is taken. The mixing requires to be done with great care, on account of the heat generated; and if the water used is not soft, and free from lime, it should be previously boiled. The solution should stand for several hours after mixing before it is put into the cells.

Working Instructions for E.P.S. Cells.

It is very important that the charging of the cells should be commenced immediately after the solution is added, and should be continued as long as possible for the first charge. Where practicable, the charging should be continued till the acid in each cell turns milky. On no account should the dynamo be stopped for the first twelve hours, nor should current be taken from the cells until the acid in every cell has turned milky, when the specific gravity will have risen at least to 1195.

It may be mentioned that the specific gravity of the acid will drop when it is first put in the cells, and will not commence to rise for a considerable time after the charging has started.

Attention must be called to a mistaken notion that the cells will last longer if they are never fully charged. It has been clearly proved that nothing tends more to destroy the plates than partly charging the cells and then completely exhausting them; so that if it is found that there is not time during the working hours to charge the cells till the acid turns a milky colour, the dynamo and engine power must be increased, or the number of lamps reduced.

The rate of discharge is estimated from the number of plates in a cell, and may be taken as about 4 amperes per positive plate of the "L" or large type plates. Thus a cell containing 15 plates is charged at the rate of from 24 to 30 amperes. For other types see special lists. The dynamo must be running at its normal speed before the cells are switched into circuit, the field magnet circuit being closed before the main circuit; and care must be taken that the cells are switched off before the dynamo is stopped.

Arrangements must be made on the switch board for varying the number of cells, both in the charging and discharging circuits.

During the discharge through the lamps, the specific gravity will be found to drop in direct proportion to the current used, thus providing a ready approximate indication of the charge remaining in the cells.

The specific gravity of each cell should be taken from time to time, and if this be done

before the charging is commenced, it will be found easy to determine the necessary number of hours' charge. For example—supposing the average specific gravity is 1170, and that it has been found that there is a rise of 6° during an hour's charge, then supposing the acid turns milky at 1210, it will be necessary to charge about six and a-half hours—*i.e.*, $\frac{1210-1170}{6}$.

If any cell is found not to turn milky as soon as the remainder, it should be cut out of circuit during the whole or part of the discharge, and then replaced. The simplest way of doing this is to disconnect one terminal of the cell and to connect the two adjoining cells by means of a piece of cable large enough to carry the discharging current. It will be found that the specific gravity at which the cells turn milky will vary slightly throughout the battery, but this will not affect the practical working.

The plates must be kept covered with electrolyte, any evaporation of which must, when necessary, be made up by the addition of pure water; but on no account should acid be added.

Evaporation will be greatly retarded by the use of glass plates covering the top of the cell, as the vapour, being condensed thereon, falls back into the cell.

It has been found from experience that *Flashing* or *Sparking* the cells with a copper cable is detrimental. To test the condition of each cell either a voltmeter should be used or the instrument specially made by the Company for this purpose. This test should be made while discharging at the normal current.

The connections throughout the battery must be kept perfectly clean, if they are not soldered

or burnt together. Brass or copper in proximity to the battery should be protected with paraffin or varnish.

On no account must the normal rate of discharge be exceeded; this is found most likely to occur when accumulators are put down for part of the lights only, and the dynamo is run with the battery as a regulator. In these cases an automatic bell alarm should be placed in the accumulator circuit.

If it is required to leave the cells out of work for any length of time, the acid must not be removed, but they must previously be fully charged, and care taken that the plates are well covered with solution. If practicable a short charging should be given, say once a fortnight, till the acid turns milky, by which treatment the cells will be kept in order for any length of time.

DYNAMOS.

By Professor Silvanus P. Thompson, D.Sc., &c.

Note.—For the sake of uniformity, Prof. Thompson has kindly adopted throughout this article the Symbols printed at the beginning of the book. Note that the first letter of words to which formulæ Symbols apply have been intentionally underlined.

Continuous Current Machines.—The E.M.F. of every dynamo depends on three matters:—

1. The quantity of the magnetic field in which the armature revolves; or, in other words, the total number of magnetic lines which the field-magnet forces through the armature.
2. The number of conducting wires or convolutions wound upon the armature.
3. The speed of rotation of the armature.

The E.M.F. being (in absolute C.G.S. measure) expressed by the number of magnetic lines cut per second, it may be conveniently calculated in any continuous-current machine of ordinary type as follows:—

Let, $\mathbf{M}_a$, stand for the *magnetisation of armature*, or magnetic flux through armature, or the whole number of magnetic lines which pass into the armature core from the north pole of the field-magnet and pass out again from the core to the south pole of the field-magnet.

Let, T_{aw}, stand for the *turns of armature wire* or the number of conductors that are in series with one another on the armature, as counted (in two pole dynamos) all round the periphery, or as counted (in multipolar machines) from a point opposite a north pole to a corresponding point opposite the next north pole of the field-magnet.

Let, n, stand for the nnmber of revolutions per minute. $\therefore \frac{n}{60}$ = revolutions per second.

Then we shall have:—

$$\text{E.M.F.} = \mathbf{M}_a \times T_{aw} \times \frac{n}{60}$$

To turn absolute E.M.F. into volts we must divide by 10^8;

Let, E_a, stand for the E.M.F. generated in armature.

$$\therefore E_a \text{ (volts)} = \frac{M_a \times T_{aw} \times n}{60 \times 10^8}.$$

EXAMPLE I.—A certain dynamo by Mather & Platt is magnetised so that 4,000,000 magnetic lines are forced through the armature core by the field-magnets; it has 160 convolutions on a ring-armature, and is run at a speed of 1,050 revolutions per minute.

Its E.M.F. is therefore—

$$E_a = \frac{4{,}000{,}000 \times 160 \times 1{,}050}{60 \times 100{,}000{,}000} = 112 \text{ volts.}$$

The current of every dynamo depends upon:—

1. The E.M.F. which it is exerting.
2. The total resistance of its circuit, including its own internal resistance (*i.e.*, the resistance of the conducting wires of its armature and magnetising coils), as well as the nett resistance of the parts of the circuit (leads, lamps, &c.) external to the machine.
3. Any counter electro-motive forces there may be in the circuit, such as those due to accumulators being charged, or to motors being run.

Let, E_a, stand for total E.M.F. of dynamo or that in armature.

E_c, , any counter E.M.F. in the circuit.
,, R_G, ,, total resistance of generating dynamo
,, R_e, ,, nett resistance external.
,, C_e, ,, current in external circuit.

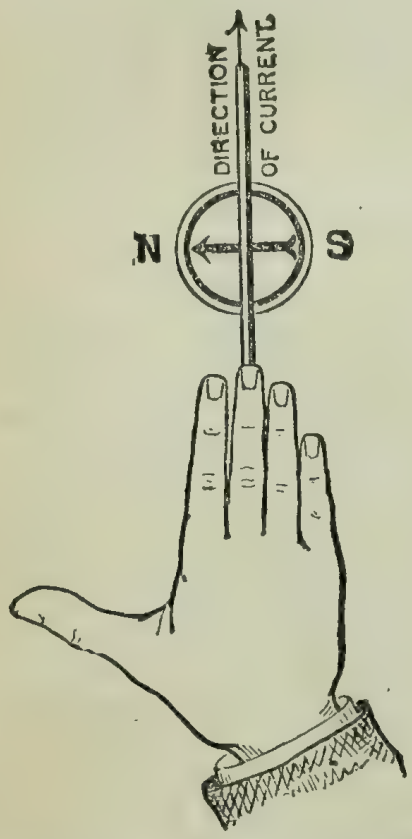
We can calculate the current in amperes (in the case of continuous current series machines) by the formula

$$C_e = \frac{E_a - E_c}{R_G + R_e} \text{ (amperes).}$$

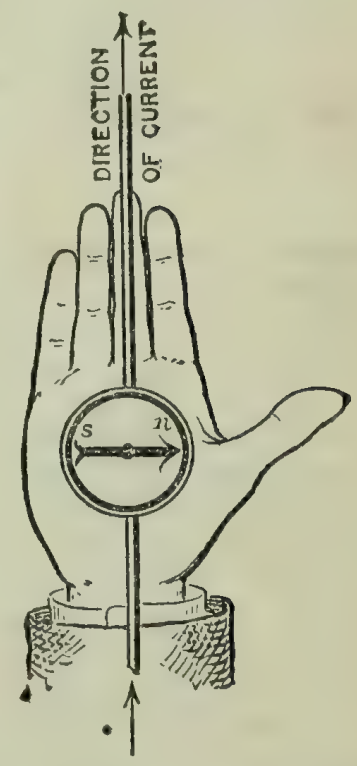
If there are no counter electro-motive forces in the circuit, as, for example, when the circuit only supplies incandescent lamps, then, E_c, may be omitted, and the formula becomes

$$C_e = \frac{E_a}{R_G + R_e} \text{ (amperes).}$$

In continuous current dynamos the armatures, whether of ring or drum pattern, are wound in *sections* connected symmetrically to a *collector* or *commutator*, which usually consists of parallel bars of copper carefully insulated from one another, and against which press the *brushes* by which the current is taken off at one side to the circuit, and returned, at the other side, from the circuit to the machine.



RIGHT HAND ABOVE THE CONDUCTOR.
NEEDLE BELOW THE CONDUCTOR



RIGHT HAND BELOW THE CONDUCTOR.
NEEDLE ABOVE THE CONDUCTOR.

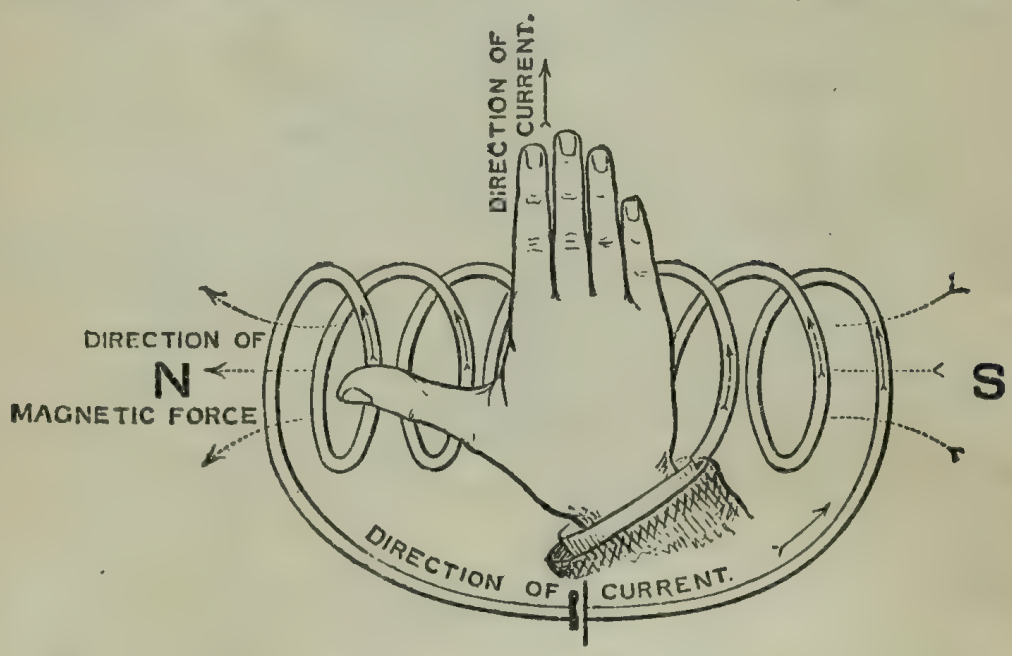
The brushes are arranged to press on the commutator at the positions known as the *neutral points* (points of least-sparking), and as the bars of the commutator pass successively under the brush, the sections of the winding are successively commuted. The separate sections in the armature winding may be compared to the separate cells in a voltaic battery, the electro-motive force of any row or series of them being the sum of the electro-motive forces of the separate parts of the series. But in the case of the moving sections, their electro-motive forces are not equal, they are continually rising, falling, and alternating. In a well-designed dynamo the neutral points are close to the positions where the induced electro-motive forces in the rotating sections have zero values, and the commutation

of each section occurs just after the direction of the induced electro-motive force in that section reverses itself.

Direction of Currents in Conducting Wires.*

1. Move the conductor (if possible) into the magnetic meridian (see last fig.)
2. Place a freely suspended compass needle below or above the wire. The current will deflect the, N, pointing end of the needle to the left or to the right.
3. Place the palm of the *right* hand next the wire (but on the opposite side to the needle) so that the outstretched thumb coincides in direction with the deflected. N, pointing pole of needle. Then the current flows along the wire in the direction indicated by the arrows *to* the negative (—) pole of the dynamo or battery.

Polarity of a Solenoid or Core and Direction of Current.



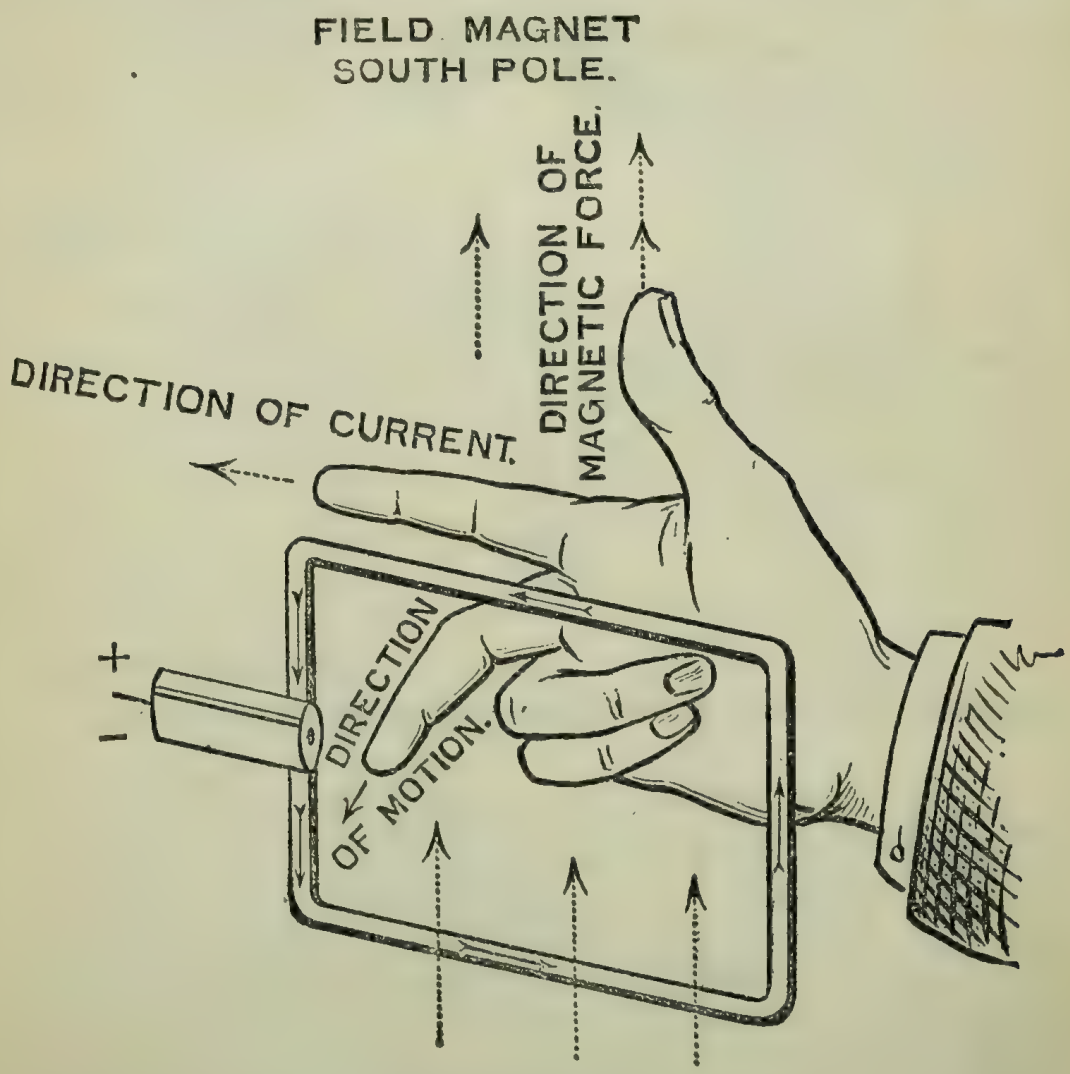
B

1. By a compass-needle ascertain the, N, pole of the solenoid or core.
2. Place the palm of the *right* hand on the solenoid with outstretched thumb in the direction of the, N, pole (or where the magnetic lines leave the solenoid or core). Then, the direction of the current from the generator or battery, B, flows as shown by the above figure.

* These four rules for the direction of currents, &c., in wires, solenoids, dynamos and motors are modifications of Dr. Fleming's rules by Professor Jamieson.

3. If we know the direction of the current in the winding, then by placing the *right* hand as shown, the thumb points in the direction of the, N, pole of the solenoid or core.

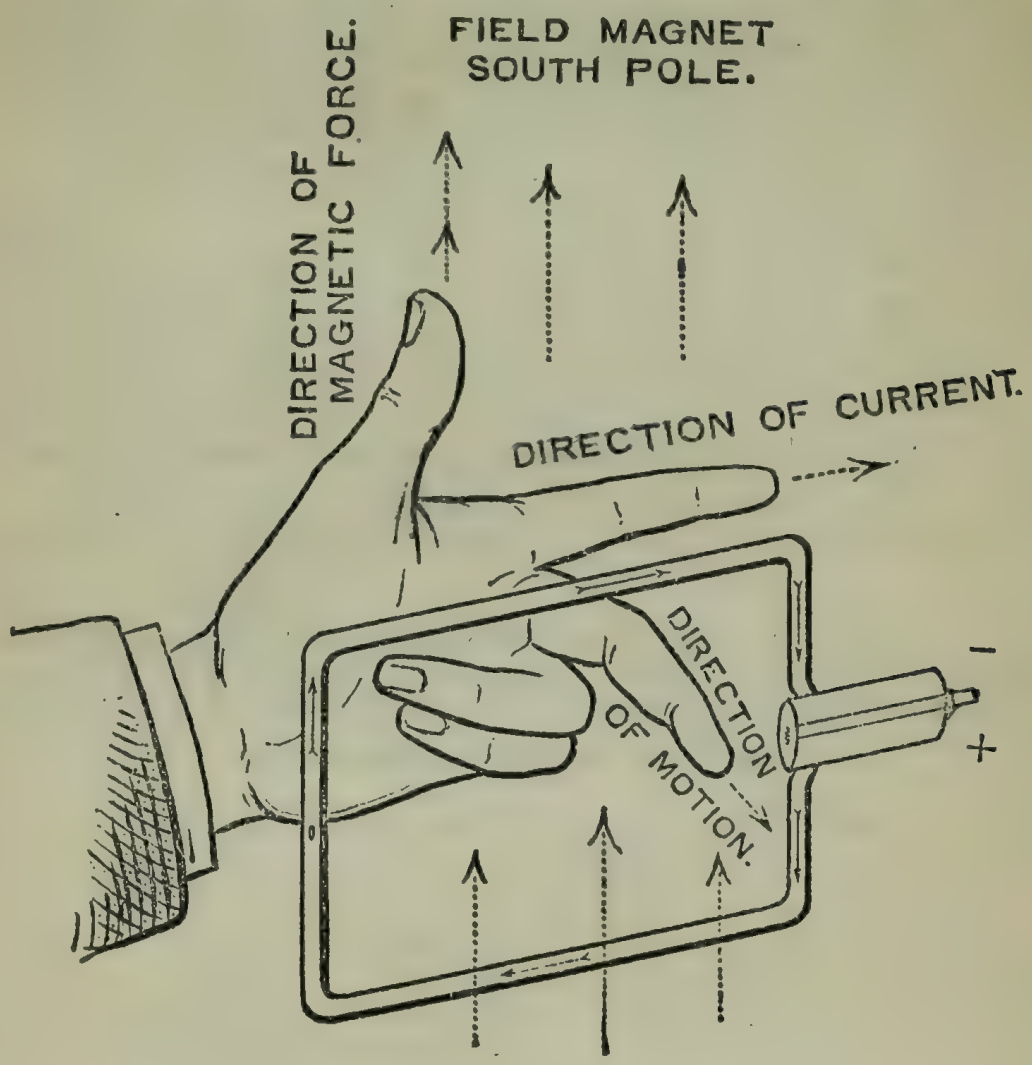
Direction of Current in a Dynamo Armature.—Knowing the direction of the magnetic lines of force, by a compass-needle and the direction of rotation,



DYNAMO · RIGHT HAND.

place the right hand as shown. Then the outstretched *fore*-finger (as in the above figs.) gives the direction of the current in the armature conductors, and therefore how the current leaves and enters the commutator.

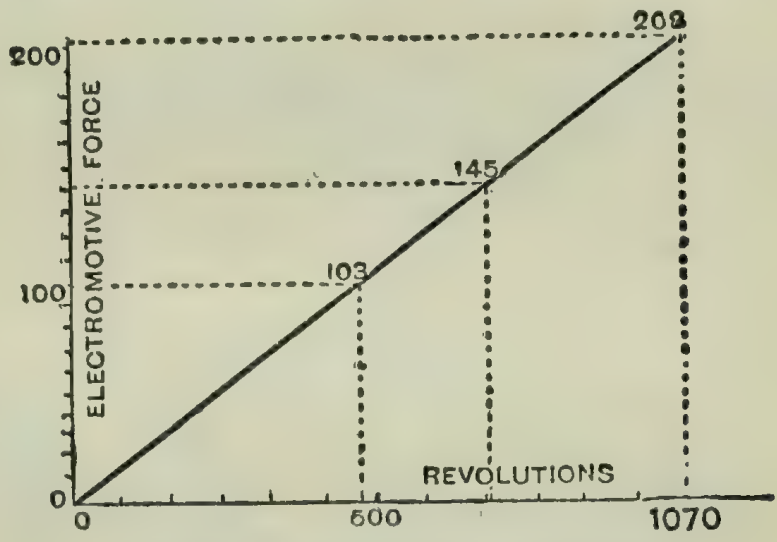
Direction of Rotation of the Armature in an Electric Motor.—Knowing the direction of the magnetic lines of force by a compass-needle, and the direction



MOTOR LEFT HAND.

of the current in the armature, place the left hand as shown. Then the outstretched middle finger gives the direction in which rotation will take place.

Curve Showing Relation between Speed and E.M.F.—Theory indicates that in a magneto-electric machine the E.M.F. induced in the armature should be exactly proportional to the speed of rotation, provided the magnetic field in which the armature rotates is of constant intensity. This is only true if the current in



MAGNETO-ELECTRIC MACHINE.

the armature is kept constant by increasing the resistance of the circuit in proportion to the speed, because currents of different strength react unequally on the intensity of the field. *Example*—

Speed, . .	500 . .	720 . .	1070 revols. per min.
E.M.F., . .	103 . .	145 . .	208 volts.

Alternate-current Machines.—These machines instead of producing a steady flow of current in one direction through the circuit throw off rapid waves of current which pulsate round the circuit first in one direction, then in the other. Or, more strictly, they set up waves of alternately directed electro-motive force. Whether the resulting waves of current are large or small in amount depends upon the properties of the circuit. It is found as a fact, that the *resistance* (ohms) of the circuit is not the only thing that impedes the setting-up of these alternate waves, but that the electric *inertia* of the circuit (otherwise called its *self-induction*) must be taken into account. It is also found that the more rapid the alternations, the more does the inertia (or self-induction) of the circuit impede the waves of current. It is possible to distinguish two separate effects due to this inertia.

1. The waves are retarded or changed in phase.

2. The waves are actually diminished in amplitude or strength, as though the inertia added something to the resistance.

If L_s stand for the *coefficient of self-induction* of the circuit (see index for how to measure).
" n, " the number of complete *alternations* or complete cycles per second (*i.e.*, the number of revolutions per second × the number of pairs of poles around the machine).

Then the inertia is reckoned as equal to

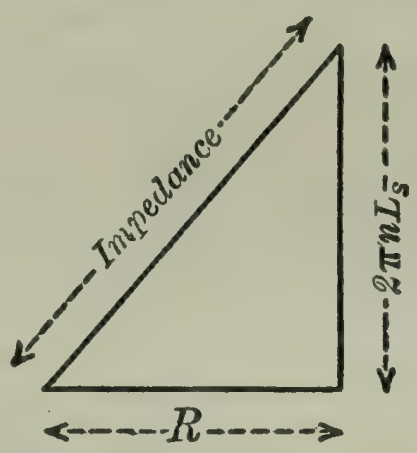
$$2\pi n L_s.$$

Also, the whole *impedanæ* is calculated as follows:—

$$(\text{Impedance})^2 = (\text{Inertia})^2 + (\text{Resistance})^2$$

Or, $$\text{Impedance} = \sqrt{4\pi^2 n^2 L_s^2 + R^2}$$

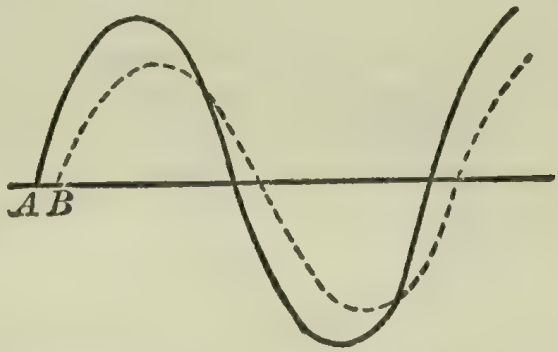
Or, geometrically, if two sides of a right-angled triangle are drawn to scale to represent resistance and inertia, the hypotenuse will represent the total impedance. Another important property of this triangle is that the angle, ϕ,



whose tangent is the ratio of inertia to resistance represents the retardation of phase (a whole period of alternation from wave to wave being represented by a whole circumference). So in this case we must calculate the currents furnished by the machine by the following modification of Ohm's law:—

$$\text{amperes (alternating)} = \frac{\text{volts (alternating, retarded)}}{\text{impedance of circuit}}.$$

To express for purposes of calculation the waves of alternating E.M.F. and current requires the use of sines and cosines. We may take it as sufficiently accurate that in a well-designed alternate current dynamo the rise and



WAVES OF E.M.F. AND CURRENT.

fall of the waves of electro-motive force is fairly represented by a curve of sines or of cosines, time being plotted horizontally and volts vertically. Then the two effects noted above as due to inertia are both indicated by the dotted curve, showing waves retarded and diminished. It is clear from the triangle that the retardation in phase can never exceed $\frac{\pi}{2}$ (*i.e.*, a right-angle) or one quarter of a whole wave.

To reckon the electro-motive force from the speed and construction of the machine we must know three things—

1. $\mathbf{M}_a$, the *magnetisation* of armature or number of magnetic lines that pass through *any one* of the branches of the magnetic circuit (*i.e.*, that come into the armature from any one of the north-poles or pass out from any one of the south-poles of the field-magnet).

2. T_{aw}, the turns of armature wire or the total number of coils on the armature that are in series with each other.

3. n, the number of alternations per second.

If we know these, then the E.M.F. in volts, at any short time, t, after the armature coils have passed from the point of symmetry opposite the field-magnet pole, would be given by the expression

$$\text{E.M.F. (volts)} = \mathbf{M}_a \times T_{aw} \times n \times 2\pi \cdot \sin 2\pi n t \div 10^8;$$

Or, rather, this is the E.M.F. at that instant if there were no retardation due to inertia.

When $t = o$, the E.M.F. also $= o$.

When $t = \frac{1}{4}$ of $\frac{1}{n}$, or a quarter of an alternation, and the E.M.F. is at its maximum,

$$\sin 2 \pi n t = 1.$$

As the sine varies from, $+1$, to, -1, so the E.M.F. varies from

$$+ 2 \pi n \, \mathbf{M}_a \cdot T_{aw} \text{ to } - 2 \pi n \, \mathbf{M}_a \cdot T_{aw}.$$

For convenience, we may write, θ, for $2 \pi n t$. The angle, θ, on the circle of reference increasing as, t, increases, one revolution round this circle corresponding to one complete alternation of the induction of the machine.

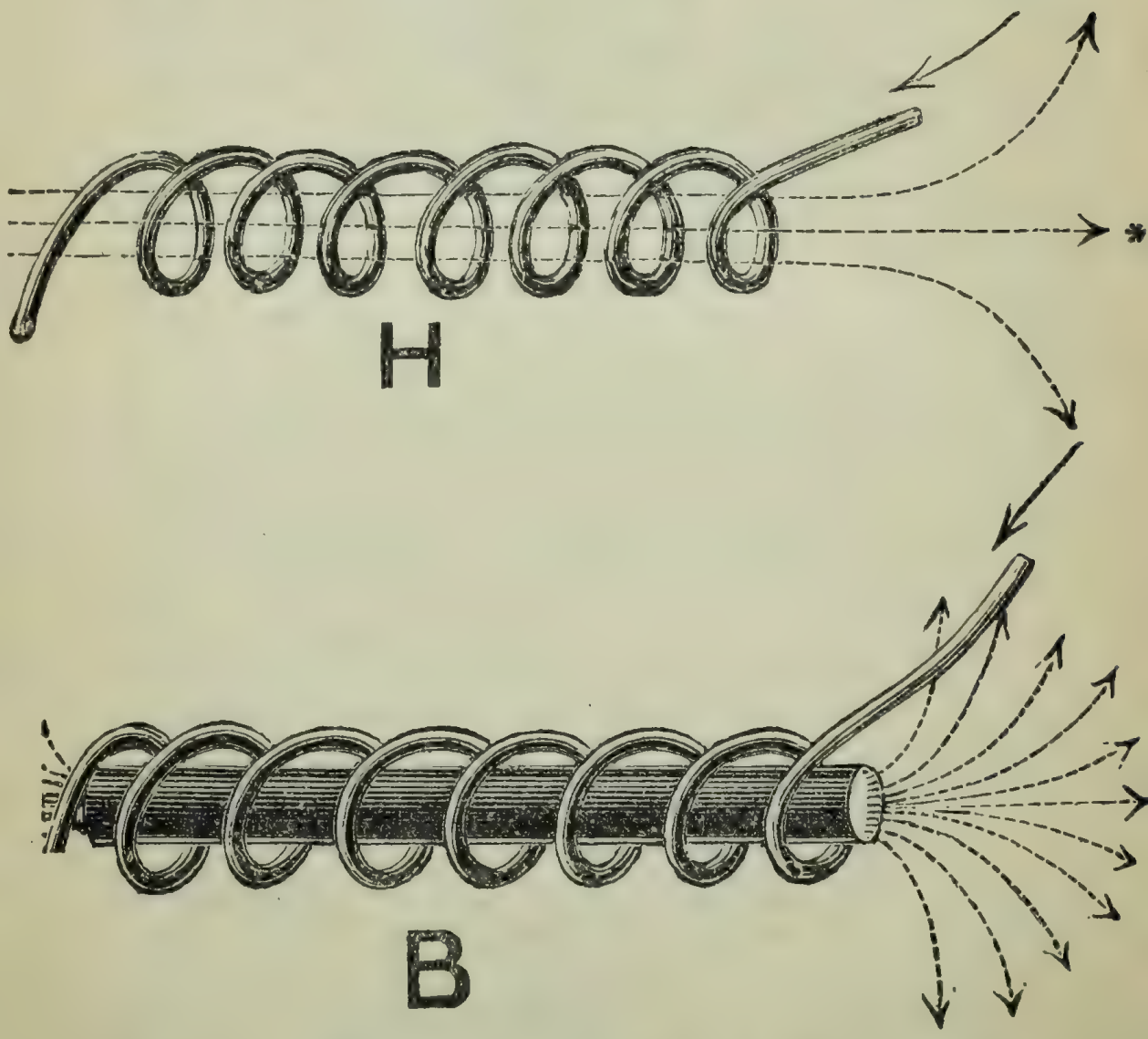
Hence we may finally write

$$C \text{ (amperes)} = \frac{\mathbf{M}_a \cdot T_{aw} n \times 2 \pi \cdot \sin (\theta - \phi)}{\sqrt{4 \pi^2 n^2 L_s^2 + R^2} \times 10^8}$$

Field-Magnets.—In the preceding paragraphs the symbol, $\mathbf{M}_a$, is used for the magnetisation of the armature or the total quantity of magnetic lines that are forced into the armature core from a north-pole of the field-magnet (and pass out again to a south-pole of the field-magnet). Continental writers term this the *magnetic flux;* some English writers call it the *total magnetic induction*, others call it the *quantity of the magnetic field.* The number varies in different machines, and obviously depends on the degree of excitation of the machine. In designing dynamos it is most important that this quantity should be as great as possible. Hence, whether for continuous or alternate-current machines, the knowledge of this quantity is of much importance to the engineer. To ascertain the value of, $\mathbf{M}_a$, in any existing dynamo, the simplest method is to run the machine at a known speed, and measure, E_e, with a voltmeter, then calculate, $\mathbf{M}_a$, by the formula on the second page of this article, or for alternate current machines, that on preceding page. In order to predetermine, $\mathbf{M}_a$, from the working drawings of the machine, it is necessary firstly, to know something of the

properties of iron in general, and in particular of the iron of which the dynamo is to be built; and secondly, to apply the principle of the magnetic circuit.

Magnetic Properties of Iron.—All kinds of iron and steel possess to greater or less degree the property of magnetic *permeability*, that is to say, of favouring the con-



duction of magnetic lines of force. If a helix or solenoid of copper wire is traversed by an electric current, its interior is observed to exhibit magnetic properties; magnetic lines running longitudinally through it. If a core of iron is now placed inside the coil the magnetism is observed to be greatly increased.

* These two figures are from *The Electrician*.

Let H stand for the number of magnetic lines per square centimetre of sectional area without iron core.

" B " the number of magnetic lines per square centimetre in the iron when the iron core is put into the solenoid.

" μ " the permeability.

Then if, B, is many times greater than, H, we call the iron very permeable. The name *permeability* (symbol μ) is given to the ratio of B to H. For soft wrought-iron, μ, is greater than for harder qualities, or for steel. The number of magnetic lines that can be crowded into a bar of iron or steel, per square centimetre, depends partly on the magnetising force and partly on the permeability of the particular sample of iron; and the latter varies with the degree of saturation. From a certain point (about where B = 7000, in wrought-iron) the permeability diminishes, so that additional magnetising force does not produce a proportionately great additional induction. There is a practical degree of saturation in various qualities of iron, beyond which the magnetisation cannot be forced except by the application of abnormally great magnetising forces.

For grey cast-iron, the practical limit is when B = about 10000 (lines per square centimetre), and for soft wrought-iron the practical limit is about when B = 18,000; though Ewing, by special devices, has more than doubled this limit. The values of, μ, corresponding to various values of, B, have been ascertained by sundry experiments.*

* See Bidwell, *Proc. Roy. Soc.;* Hopkinson. *Phil. Trans.*, 1885, Pt. 2, p. 455; Silvanus Thompson's Dynamo-Electric Machinery (edition of 1888), p. 288, for summary of researches. Also, see the chapter on Magnetic Measurements, at end of this Pocket-book.

The following table, calculated from Hopkinson's results, will be found useful:—

Annealed Wrought-Iron.			Grey Cast-Iron.		
B	H	μ	B	H	μ
5,000	2	2,500	4,000	5	800
9,000	4	2,250	5 000	10	500
10,000	5	2,000	6,000	21·5	279
11,000	6·5	1,692	7,000	42	133
12,000	8·5	1,412	8,000	80	100
13,000	12	1,083	9,000	127	71
14,000	17	823	10,000	188	53
15,000	28·5	526	11,000	292	37
16,000	52	308			
17,000	105	161			
18,000	200	90			
19,000	350	54			

In the case of this sample of wrought-iron, the values of, μ, corresponding to the values of, B, between 6,000 and 16,000 are approximately calculable from the formula—

$$\mu = (17{,}000 - B) \div 3{\cdot}5.$$

It will not, however, do to assume that these figures will suit every sample of wrought-iron; they vary in every brand.

For air the permeability is taken as = 1, the number of magnetic lines to the square centimetre being numerically equal to the magnetising force, either of them being called

H. This is calculated from the ampere-turns of the magnetising current as follows:—

Let, C, stand for the current in amperes, passing through spiral.
" T_w, " turns of wire, or number of turns in the spiral.
" l, " length of spiral in centimetres.

Then if the spiral is long compared with its diameter, the value at any internal point is,

$$\mathbf{H} = 4\pi T_w C \div 10\,l = 1{\cdot}257 \times \text{ampere-turns per c.m.}$$

When, however, we are dealing with the whole magnetising force of a coil or set of coils, it is more directly useful to have an expression for the *total magnetising force* of the whole spiral than merely for its intensity at any particular point. Hence the formula is preferable in the form.

Total magnetising force $= \mathrm{H}\,l =$ total ampere-turns $\times 1{\cdot}257$.

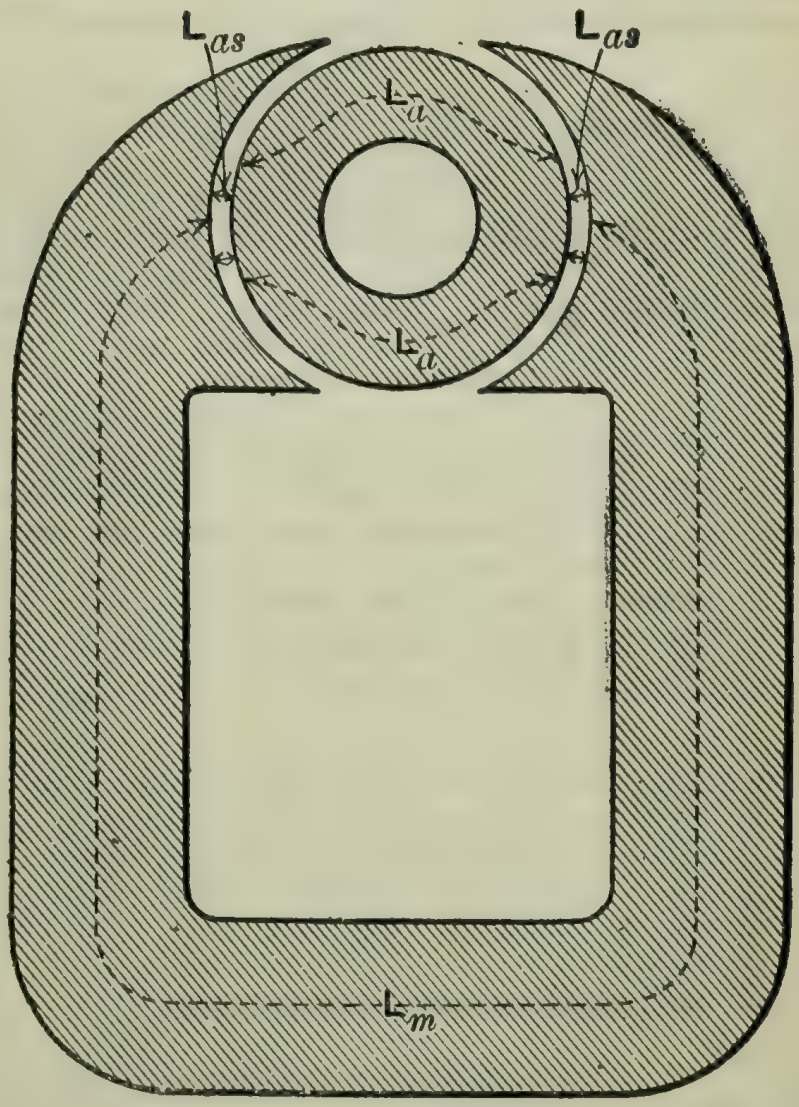
Principle of the Magnetic Circuit.—The iron cores of the field-magnet and armature, together with the air spaces between them constitute a *magnetic circuit* along which the magnetic lines pass. The magnetic flux, $\mathbf{M}_F$, or whole number of magetic lines flowing along this circuit can be calculated (by a process resembling calculations by Ohm's law for electric circuits), if the exciting force or *magneto-motive force*, and *the sum of the magnetic resistances* is known. Now the magneto-motive force is nothing else than the total (or "line integral") of the magnetising forces mentioned above: and the total magnetic resistance is simply the sum of the separate magnetic resistances of the parts of the magnetic circuit.

The *magnetic resistance* of any magnetic conductor is proportional directly to its length and inversely to its cross section and permeability.

Let, **L**, stand for the length of the magnetic circuit passing through any piece of iron.
" **S**, " section of the magnetic circuit passing through any piece of iron.
" μ, " permeability of that piece of iron.

Then its magnetic resistance $= \dfrac{\mathbf{L}}{\mathbf{S}\mu}$.

As an example of a magnetic circuit we take that of a dynamo-machine in which the magnetic resistances are three: (1) the field-magnet cores; (2) the armature-core; (3) the gaps between them, as shown by the figure.



Let, L_m, S_m, μ_m refer to the field-magnet part of the magnetic circuit.

" * L_{as}, S_{as}, μ_{as} " air space part of the magnetic circuit.

" L_a, S_a, μ_a " armature part of the magnetic circuit.

* The length across each of the air spaces being, L_{as}, and the exposed area of polar surface at either pole being, S_{as}.

$$\text{Total magnetic res.} = \frac{L_m}{S_m \mu_m} + 2\frac{L_{as}}{S_{as} \mu_{as}} + \frac{L_a}{S_a \mu_a}$$

But the law for the magnetic circuit is:—

$$\left.\begin{array}{l}\text{The Magnetic flux or}\\ \text{Total number of}\\ \text{magnetic lines}\end{array}\right\} = \frac{\text{Magneto-motive force}}{\text{Magnetic resistance}}$$

$$M_F = \frac{1{\cdot}257\ T_w\ C}{\dfrac{L_m}{S_m \mu_m} + 2\dfrac{L_{as}}{S_{as} \mu_{as}} + \dfrac{L_a}{S_a \mu_a}}$$

Application to Designing of Dynamos.—Suppose in designing a dynamo, it has been decided what will be a convenient speed, how many conductors shall be wound upon the armature, and what quantity of magnetic lines there must be in the field, it then becomes necessary to calculate the sizes of the iron parts and the quantity of excitation to be provided for by the field-magnet coils. It being known what, M_F, is to be, the problem is to design the machine so as to get the required value. Experience shows that, in every type of dynamo, there is magnetic leakage, some of the magnetic lines created by the field-magnet leaking across instead of going through the armature. Experience also shows that it is not wise to push the saturation of the armature core to more than 16,000 lines to the square centimetre at the most highly saturated part, and that the induction in the field-magnet ought to be not greater than this, even allowing for leakage. Leakage may amount to, $\frac{1}{4}$, of the whole: hence, if the magnet cores are made of same quality of iron as the armature cores their cross-section ought to be at least, $\frac{5}{4}$, as great as that of the armature core at its narrowest point. If the field-magnets are of cast-iron the section ought to be at least twice as great.

Now, B_a (the induction in the armature core) $= \dfrac{M_a}{S_a}$;

Hence, if this is fixed at 16,000 lines per centimetre of cross section we at once get

$$S_a = \frac{M_a}{B_a}.$$

This fixes the cross-section of the armature core. (Example, if $M_a = 4{,}000{,}000$ of lines, then there must be a cross-section equal to 250 square centimetres for $\dfrac{4{,}000{,}000}{16{,}000} = 250$.)

Magnetic Length of Armature Circuit.—The size of wires on the armature is fixed by the number of amperes which it must carry without risk (see index for safe currents): remembering that only half the current (in ring or drum armatures) passes through any one coil, and as the number is supposed to have been fixed beforehand, this practically settles the quantity of copper that must be put on the armature, and experience dictates that the core should be made so large that the thickness of the external winding does not exceed, $\frac{1}{6}$, of the radial depth of the iron core. This settles the size of the armature core, from which an estimate of, L_a, the average length of path of the magnetic lines in the core can be made.

Length and Section or Surface Area of Air Space.—Experience further dictates the requisite clearance, and the advantage of making the pole-pieces subtend an arc (in two-pole machines) of at least 135° each, so as to gain a large polar area. This settles, L_{as}, and, S_{as}.

Length of Field-magnet Iron Cores, &c.—As shown above, the minimum value of, S_m, is settled by leakage and materials; L_m, therefore remains to be decided. It is clear that the magnet cores must be long enough to allow of the requisite magnetising coils, but should not be longer. As a rule, they are made so stout, especially in the yoke part, that they do not add much to the magnetic resistance of the circuit, then a little extra length assumed in the calculation does not matter much. It now only remains to calculate the number of ampere-turns of excitation for which it will be needful to provide.

It will now be more convenient to rewrite the formula of the magnetic circuit as follows:—

$$A \times T_{mw} = M_a \frac{\left\{ \lambda \frac{L_m}{S_m \cdot \mu_m} + 2 \frac{L_{as}}{S_{as} \cdot \mu_{as}} + \frac{L_a}{S_a \cdot \mu_a} \right\}}{1{\cdot}257}$$

Where, A, stands for the amperes of current passing through the field-magnet coils.

" T_{mw}, " total turns of the magnet wire.

" λ, " leakage coefficient (say $\frac{5}{4}$) mentioned above.

Or,

$$A \times T_{mw} = M_a \frac{\lambda R_m + R_{as} + R_a}{1{\cdot}257}$$

Or, as before,

$$M_a = 1{\cdot}257 \frac{A \times T_{mw}}{\lambda R_m + R_{as} + R_a}$$

Where, R_m, R_{as}, R_a stand for the magnetic resistance of magnets, air space, and armature respectively.

But we cannot use this formula yet because the values of, μ, in it depend on the degree of saturation of the iron in the various parts. These have to be found from the Hopkinson tables in this article; and, indeed, it is preferable first to rearrange the formula once more, by dividing it into its separate members, ascertaining separately the ampere-turns requisite to force the required number of magnetic lines through the separate parts, and then add them together.

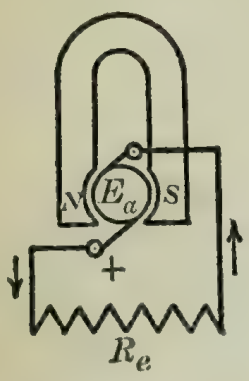
1. Ampere-turns required for magnet cores, . . $\Big\} = \lambda \dfrac{M_a}{S_m} \times \dfrac{L_m}{\mu_m} \div 1{\cdot}257$

2. Ampere-turns required for air-spaces, . . . $\Big\} = \dfrac{M_a}{S_{as}} \times 2 \dfrac{L_{as}}{\mu_{as}} \div 1{\cdot}257$

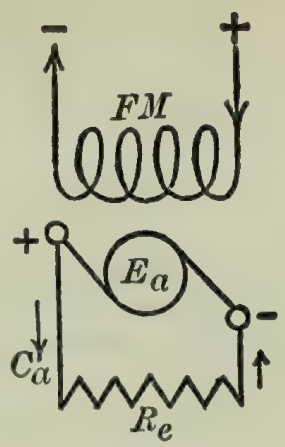
3. Ampere-turns required for armature core, . . . $\Big\} = \dfrac{M_a}{S_a} \times \dfrac{L_a}{\mu_a} \div 1{\cdot}257$

Now, $\lambda \dfrac{M_a}{S_m}$, is the value of B in the magnet cores, and reference to table will show what the corresponding value of, μ_m, must be: similarly, $\dfrac{M_a}{S_a}$, will afford a clue to μ_a.

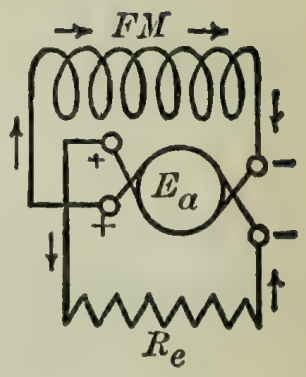
When the total number of ampere-turns to be allowed for is thus ascertained, the size and length of wire will be determined by the permissible rise of temperature, and the mode of exciting the field-magnets, whether in series, or as a shunt machine, or with a compound winding.



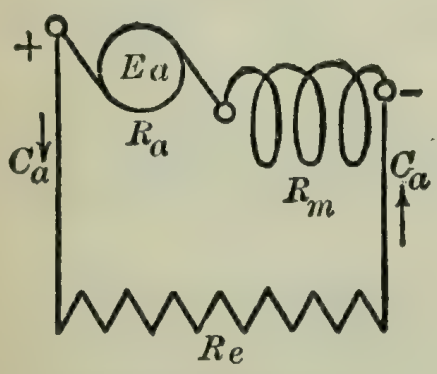
MAGNETO MACHINE.



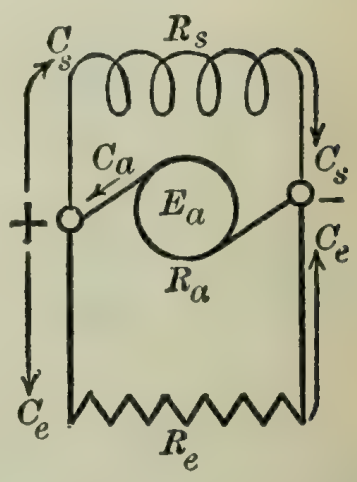
SEPARATELY-EXCITED MACHINE.



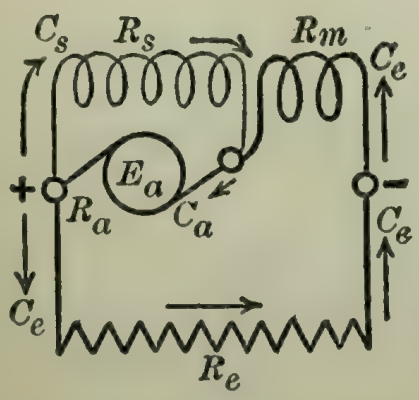
SEPARATE-COIL MACHINE.



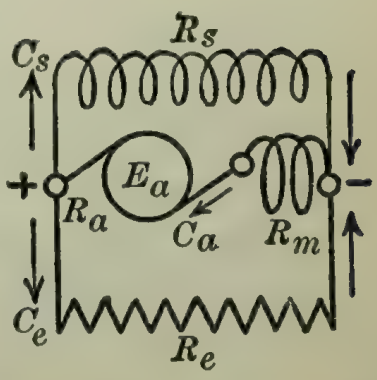
SERIES MACHINE.



SHUNT MACHINE.



SHORT-SHUNT COMPOUND.



LONG-SHUNT COMPOUND.

Methods of Connecting up Dynamos.

Continuous-Current Dynamos :—

1. *Magneto Machines.*—With permanent steel magnets.
2. *Separately-excited Machines.*—Field-magnet coils supplied with exciting currents from some external source.
3. *Separate-coil Machines.*—Field-magnet coils excited by currents generated in some windings on the armature distinct from those windings which furnish current to the outside circuit.
4. *Series Machines.*—Field-magnet coils included in the main circuit, and excited by the whole current furnished by the armature.
5. *Shunt Machines.*—Field-magnet coils arranged as a shunt to the external circuit, a small portion of the whole current only being led through the shunt.
6. *Compound-wound Machines.*—Field-magnet coils in two sets, one in series, the other as a shunt. There are two varieties, known as *long-shunt*, where the shunt coils are connected across the terminals of the main circuit; and *short-shunt*, where they are connected across the brushes of the machine.

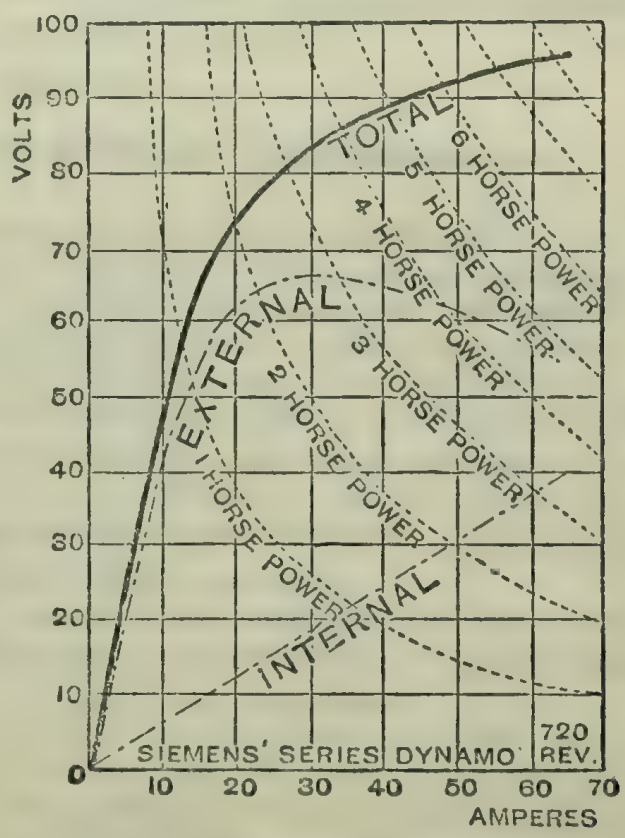
Alternate-Current Dynamos :—

1. *Magneto Machines.*
2. *Separately-excited Machines.*
3. *Separate-coil Machines.*—Field-magnets excited by currents generated in some of the armature coils, which are rectified by the use of a special commutator.
4. *Compensated Machines.*—Field-magnets excited partly by currents from separate coils on the armature, as above, partly by currents from a small transformer, the primary of which is in the main circuit; both currents being rectified by the use of a special commutator.

Alternate-current Dynamos are usually separately-excited from a small continuous-current machine. The "compensated" machine may be arranged to give constant (average) potential at the terminals of the machine.

Continuous-current Dynamos.—Series machines are now seldom employed, except for arc lighting. For incandescent lighting either shunt dynamos or compound-wound dynamos are preferred. In series-wound machines the current increases and the E.M.F. rises when the resistance of the circuit is lowered. This is best understood by studying the characteristic curve of such a machine driven at some particular speed.

Dr. John Hopkinson was the first to suggest the representation of the properties of a dynamo, or the relations subsisting between the E.M.F. and the current by curves, to which M. Marcel Deprez gave the name of "characteristic."



CHARACTERISTIC CURVE.

In the fig. the horizontal line, 0—70, represents the current in amperes, the vertical line, 0—100, the *total* E.M.F. in volts, as found by multiplying the total resistance in circuit (including the dynamo) by the current in amperes, from which the TOTAL curve is found by plotting these values for a constant speed, 720 revolutions.

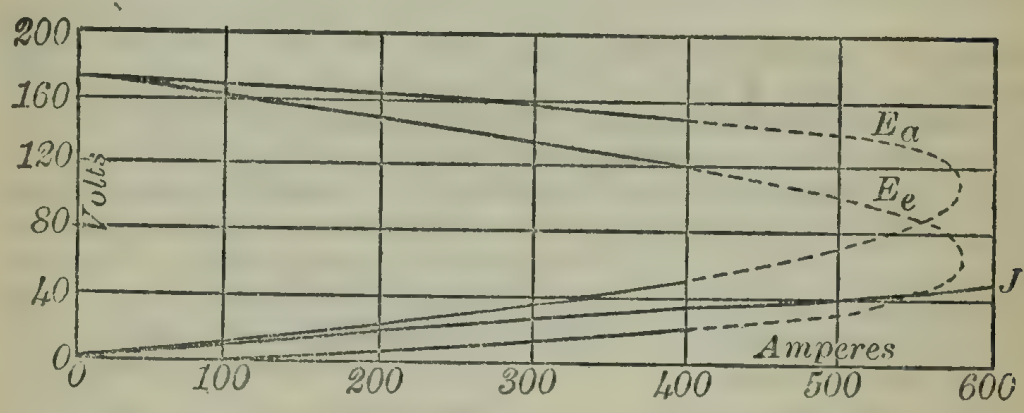
The curve marked INTERNAL is plotted out by multiplying the resistance of the armature ·6 ohm by the current

which gives the E.M.F. required for overcoming the resistance of the armature alone, and therefore the tangent of this slope represents the resistance of the armature.

The curve marked EXTERNAL was found, in this instance, by deducting the E.M.F. of the INTERNAL curve from the TOTAL, but it is usually found by simply measuring the difference of potentials between the terminals of the dynamo by means of a voltmeter, and the current passing through the external circuit by means of an amperemeter simultaneously. *The volts and amperes should always be drawn to the same scale in order to compare the curves from different dynamos.*

The curves marked HORSE-POWER are found by plotting out on the squared paper the products of the E.M.F. and current for each point, and dividing by 746. For example, the 1 horse-power will pass through all points for which the product of the volts and amperes = 746; it will, therefore, pass through the point corresponding to 74·6 volts and 10 amperes, or through 37·3 volts and 20 amperes, and so on, for the other horse-powers.

For a complete description of such curves, see Prof. Silvanus P. Thompson on *Dynamo Electric Machinery; Proc. Inst. Mech. Engineers*, April, 1879, p. 249 and 1880, p. 266; *La Lumière Electrique*. 5th Jan., 1884; *Elektrotechnische Zeitschrift*. papers by Dr. Frölich, 1881, and *Proc. Inst. C.E.*, Lecture by Dr. Hopkinson on Electric Lighting, 1883.



CHARACTERISTIC CURVE SHUNT DYNAMO.

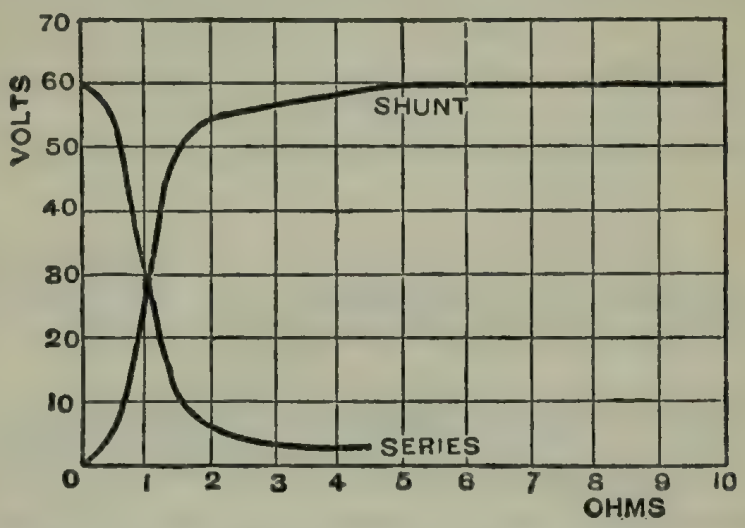
This figure gives two characteristic curves of a gramme shunt-wound dynamo, the upper one showing the relation between the whole E.M.F. of the armature and the current in the circuit, the lower one (marked *e*) showing the relation between the potential at the terminals, and the external current. It will be noticed that as the current increases

from 0 to 400 amperes the whole E.M.F. falls from 170 to 1·0 volts, and the terminal potential falls to 120 volts. The slope of the line, O J, represents the armature-resistance, and the *volts lost* in the machine itself in driving the current through this resistance are the heights of the ordinates below this line, and are equal to the corresponding distances between the two curves of total E.M.F. and potentials at the terminals. The lower branches of the curves correspond to the unstable state of excitation with very small resistance. The resistance of the shunt magnet coils should be very great, never less than 300 times that of the armature; in many machines it is 1000 or 1200 times as great. Contrasting the behaviour of series-wound and shunt-wound machines it will be seen that when more current is drawn from a series-machine the potential at the terminals first rises to a maximum, then falls, whilst with a shunt-machine, as more current is drawn the potential drops slightly.

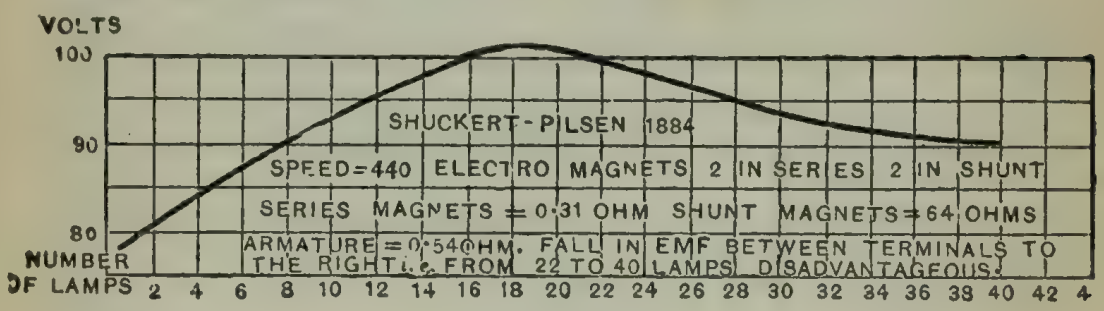
If a well-designed shunt-dynamo is built with *excessively small resistance in the armature*, the drop in potentials may be so small that the machine is nearly self-regulating. To attain more accurate *constancy of potential* than is possible with either series-wound or shunt-wound machines, the compound winding is employed. Ship dynamos are almost always compound-wound. For central station work shunt-machines or separately-excited machines are often used. For electroplating no series-wound machine should ever be used, as such are liable to reverse their polarity; shunt-wound or compound-wound machines should be employed.

Constant-Potential Dynamos for incandescent lighting with lamps in parallel. As remarked above, a machine compounded with both shunt and series windings may be arranged to give nearly constant potential at the terminals. The shunt coils should be sufficient to excite up the machine to give the requisite potentials when the circuit is open; the series coils (of which there are a few, of thick wire to carry the main current) should be just sufficient to provide the additional excitation to compensate for the "lost volts," and prevent the potential from dropping when much current is drawn from the machine. Many makers now prefer to over-compensate with a little extra series winding, so that the potential rises slightly at full load. If the dynamo be not well designed, with a good magnetic circuit of really soft iron, it cannot be made to self-regulate at a constant potential with any proportion whatever of series and shunt winding.

The following fig. shows the relation between the difference of potential at the terminals and the external resistance of a series and of a shunt-wound dynamo. The series curve begins at 60 volts and falls, the shunt curve begins at 0 and rises to 60 volts. The fig. shows that, if a dynamo were wound with both series and shunt coils on the

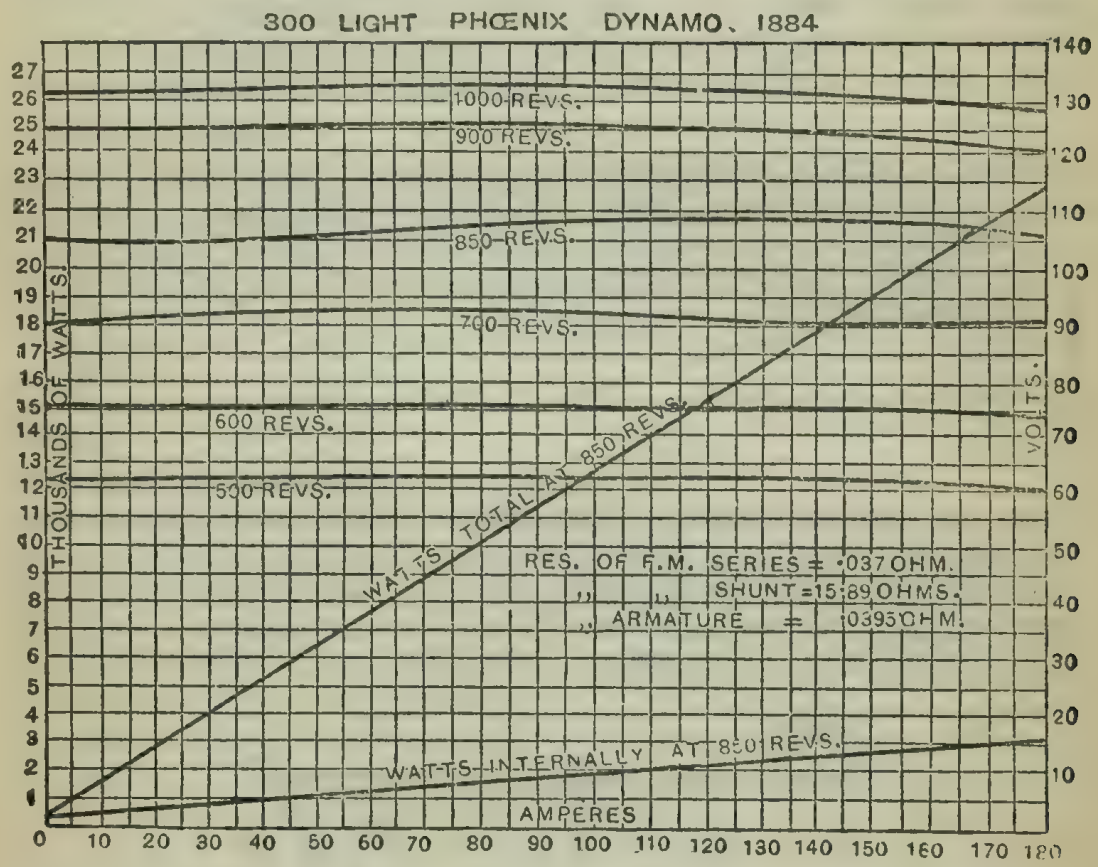


electro-magnets, so that each worked to a certain point (in the particular example given, 30 volts) at the same speed, then we should have a machine which gave a constant (30 volts) E.M.F. at that speed. This is the aim of compound (combined series and shunt), wound or self-regulating dynamos.

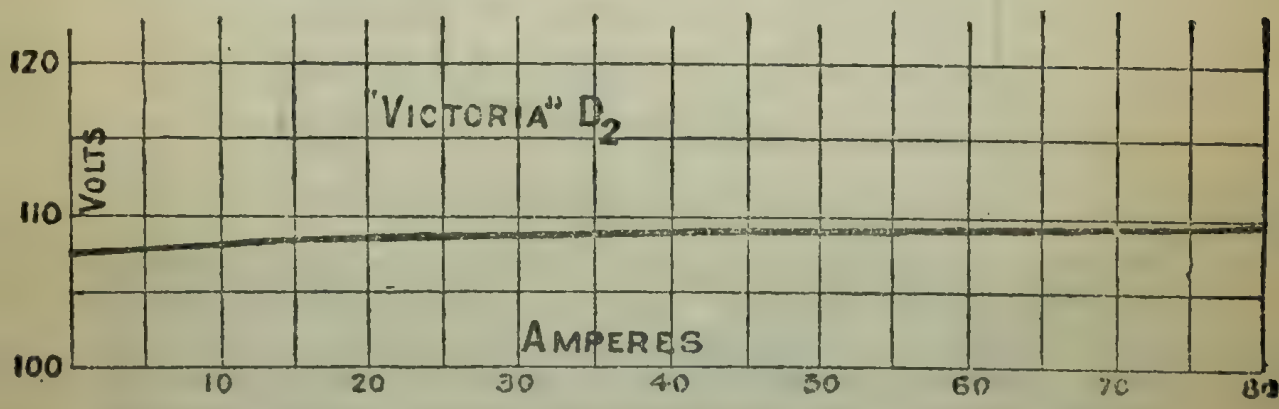


The above fig. shows the characteristic curve of a Schuckert Pilsen dynamo, where the attempt to combine the self-regulating principle has not been thoroughly carried out. The following figure shows a set of curves taken from 300 light Phœnix Dynamo by Messrs. Paterson & Cooper, wherein the self-regulating principle referred to above has been carried out almost to perfection. The data given on these figures will afford useful study to those interested in compound winding of dynamos.

The Victoria Dynamo is an interesting example, and gives a very constant E.M.F. at the terminals under circumstances for which the dynamo may have been



designed. In fact, all so-called self-regulating dynamos are only such, on the circuits for which they have been specially designed.



CHARACTERISTIC CURVE OF A "VICTORIA" D_2 DYNAMO AT 820 REVOLUTIONS PER MINUTE.

Constant-Current Dynamos.—For arc lighting in series. No one has hitherto succeeded in obtaining, by any compound method of winding, a dynamo which will always give the same number of amperes whether the lamps in series be many or few. Other devices than compound winding have to be used. For a small and constant number of arc lamps the simplest machine is a series dynamo, constructed with proportionally more copper and less iron in its field-magnets so that the working part of the characteristic curve is the drooping part beyond the maximum height. Constant current is secured in various ways by automatic regulators introduced into the main circuit. In the Brush system the automatic regulator shunts off the exciting current from the magnet coils more or less as required by the lamps in the circuit. In the Thomson-Houston system the automatic regulator shifts the position of the brushes at the commutator. In the Goolden & Trotter system the regulator shunts off through a variable resistance the exciting current from some of the coils which surround a compensating branch of the magnetic circuit.

Alternate-Current Dynamos.—The usual function of these machines is to supply currents for systems of transformers distributing low-potential currents at constant (average) potential. The dynamos feed the primary circuits of the transformers with smaller currents at a high but constant (average) potential. In the modern Ferranti machines the field-magnet consists (as in Siemens' alternate machines) of two crowns of opposing alternate poles and the armatures (formerly wound star-wise) are made of a series of ovate bobbins wound with copper ribbon. In Westinghouse's dynamo the field-magnet poles point radially inwards, surrounding an armature having a drum-core of laminated iron with copper conductors clamped over its periphery. In Mordey's alternator the field-magnet, which has but one exciting coil, and pole-pieces which present two symmetrical crowns of opposing poles, revolves, whilst the armature remains stationary.

Formulæ of Efficiency, Etc.

Total Electrical Energy (per second) of any dynamo (expressed in *Watts*) is the product of the whole E.M.F. generated by armature coils, into the whole current which passes through the armature.

Useful Electrical Energy (per second), or useful output of the machine, is the product of the useful part of the E.M.F. (*i.e*, that part which is available at the terminals of the machine), into the useful part of the current (*i.e.*, that part of the current which flows from the terminals into the external circuit).

Economic Coefficient or "electrical efficiency" of a dynamo is the ratio of the useful energy to the total energy.

Commercial Efficiency of a dynamo is the ratio of the useful energy or output, to the power actually absorbed by the machine in being driven.

Symbols.

E_a for total E.M.F. generated in armature.
E_e ,, useful E.M.F. available at terminals.
C_a ,, total current generated in armature.
C_s ,, current sent round shunt coils.
C_e ,, useful current supplied to external circuit.
R_a ,, resistance of armature coils.
R_m ,, resistance of magnet coils in main circuit (series)
R_s ,, resistance of magnet coils in shunt.
R_e ,, resistance of external circuit (lamps, mains, &c.)

Useful Notes.—When only one circuit (series machine) $C_e = C_a$.

In shunt machines, C_s, should not be more than 5°/₀ of C_e. Also $C_a = C_e + C_s$.

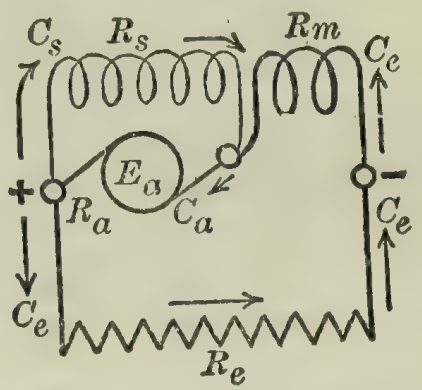
In *all* dynamos, R_a, ought to be less than $\frac{1}{40}$ as great as the working value of R_e.

In series (and compound) machines, R_m, should be not greater than, R_a, and preferably only $\frac{2}{3}$ as great.

In shunt (and compound) machines, R_s, should be not less than 300 times as great as R_a, and preferably 1000 to 1200 times as great.

	Series Machine.	Shunt Machine.	Compound Machine (Short Shunt).
Watts lost in armature,	$C_a^2 R_a$	$C_a^2 R_a$	$C_a^2 R_a$
Watts lost in magnet coils,	$C_a^2 R_m$	$C_s^2 R_s = E_e^2 \div R_s$	$C_a^2 R_m + C_s^2 R_s$
Lost volts,	$C_a R_a$	$C_a R_a$	$C_a R_a + C_e R_m$
Total electrical energy, per sec.	$E_a C_a = C_a^2 (R_a + R_m + R_e)$	$E_a C_a = C_a^2 \left(R_a + \frac{R_s R_e}{R_s + R_e}\right)$	$E_a C_a = C_a^2 \left(R_a + \frac{R_s (R_m + R_e)}{R_s + R_m + R_e}\right)$
Useful electrical output,	$E_e C_a = C_a^2 R_e$	$E_e C_e = C_e^2 R_e$	$E_e C_e = C_e^2 R_e$
Economic coefficient,	$\frac{E_e}{E_a} = \frac{R_e}{R_a + R_m + R_e}$	$\frac{C_e^2 R_e}{C_e^2 R_e + C_a^2 R_a + C_s^2 R_s}$ *	$\frac{C_e^2 R_e}{C_e^2 R_e + C_a^2 R_a + C_s^2 R_s + C_e^2 R_m}$
Commercial efficiency (percentage),	$100 \times E_e C_e \div (HP \times 746)$	$100 \times E_e C_e \div (HP \times 746)$	$100 \times E_e C_e \div (HP \times 746)$
	N.B.—Horse-power is converted into watts (so as to compare with electric output of the machine) by multiplying by 746.	*This will be a maximum when, R_e, is a mean proportional between, R_s, and, R_a.	In well-constructed compound machines the difference between "short shunt" and "long shunt" is very slight, as, R_m, is so small.

As an example of the formulæ in the foregoing table, the following calculations respecting a Rankin Kennedy short shunt compound dynamo of the form shown by the figure are given:—



The particular dynamo in question was tested by Professor Jamieson after completion, with the following results:—

Resistance of armature, warm,	R_a	=	·04 ohm.
Resistance of magnet shunt, warm,	R_s	=	20 ohms.
Resistance of magnet main coil, warm,	R_m	=	·03 ohm.
Current in main coils of external circuits,	$C_m = C_e$	=	108·5 amperes.
Current in shunt magnet coils,	C_s	=	5 amperes.
Difference of potential at dynamo terminals,	E_e	=	100 volts.
Diff. of potential at brushes,	$E_b = E_s$	=	103 volts.
E.M.F. generated in armature,	E_a	=	108 volts.
Turns of armature wire,	T_{aw}	=	180.
Number of armature revolutions per minute,	N_{ar}	=	620.

ELECTRICAL EFFICIENCIES.

External electrical power, or "output," available for electric lighting, &c.,

$$= C_e \times E_e = 108{\cdot}5_a \times 100\,\text{v} = 10{,}850 \text{ watts} = 88{\cdot}7\%$$

Power absorbed by armature,

$$= C_a^2 \times R_a = (113{\cdot}5)_a^2 \times {\cdot}04\,\omega = 515 \text{ watts} = 4{\cdot}2\%$$

Power absorbed by shunt magnet coils,

$$= C_s \times E_s = 5_a \times 103\,\text{v} = 515 \text{ watts} = 4{\cdot}2\%$$

Power absorbed by main magnet coils,

$$= C_m^2 \times R_m = (108{\cdot}5)_a^2 \times {\cdot}03\,\omega = \quad 353 \text{ watts} = \quad 2{\cdot}9\%$$

Total electrical power,

$$(C_e \times E_e) + (C_a^2 \times R_a) + (C_s \times E_s) + (C_m^2 \times R_m) \qquad = 12{,}233 \text{ watts.}$$

Management of Dynamos.

Before the dynamo is started for its day's run the lubricators should be filled up—always use copper oil-cans—and the brushes should be examined to see that they are properly trimmed and thoroughly well screwed up in their holders. Brushes that touch at a bevel angle require occasional trimming with a file to preserve an even bearing on the commutator: for trimming they should be removed from the machine. No files or iron tools should be left near the dynamo. If the dynamo is in a workshop where iron filings fly about, it should be occasionally examined to see if any filings have been attracted, and any such should be promptly removed: dynamos, if they must be placed in such positions, should be boxed up as completely as possible. *After* the machine has been started the brushes should be put down: when the run is over they should be raised *before* the engine is stopped. The commutator should be kept clean and bright, and free from metallic dust of any kind. It should be occasionally wiped with a clean piece of rag (not waste), very slightly smeared with oil or vaseline. If the brushes press too heavily it will be worn into ruts, if they do not press firmly enough its segments will wear unequally along their edges. As soon as the dynamo is started the brushes should be carefully so rocked that they touch at the neutral points: if this position is not carefully observed, the sparking may rapidly ruin the commutator.

Electric Motors.

When a dynamo is used as a motor the power is supplied to it electrically in the form of electric currents delivered at a certain potential or pressure.

If, C_M, is the number of amperes of current which flow through the motor, and,

E_M, be the number of volts of potential as measured at the terminals of the motor, then the electric power in watts, P_W, given by the mains to the motor (per second) will be found by multiplying together the amperes and the volts, or $P_W = E_M C_M$ (watts.) This may be expressed as electric horse-power by dividing by 746.

$$\text{E.H.P.} = \frac{E_M C_M}{746}.$$

All of this power electrically supplied is not, however, turned into mechanical power, some being inevitably used up in heating the conductors (because they have electric resistance) and in magnetic friction. That part of the power which is actually utilised in turning the armature may be expressed in two ways, either electrically or mechanically.

If, C_a, is the amperes that flow through the armature, and, E_a, the E.M.F. actually generated by the rotation of the armature as it goes round in its magnetic field, then the number of watts utilised is

$$P_w = E_a C_a.$$

The efficiency (electrical) of the motor is given by the ratio of P_w to P_W or $\frac{P_w}{P_W}$. The power thus utilised in the armature, if expressed in electrical horse-power, will be

$$E_a C_a \div 746.$$

To express in mechanical units the power utilised by the armature, it must be remembered that the power is also the product of two factors, the speed and the turning-moment or torque.

If, n, stand for the number of revolutions per minute, and
F_{pf}, " torque, or force in pound-feet—*i.e.*, so many pounds' weight acting at a radius of one foot,

Then the number of foot-pounds per minute is given by 2π times the product of, n, and, F_{pf}.

Or,
$$\text{H.P.} = \frac{2\pi n F_{pf}}{33{,}000}.$$

Equating this to the electrical expression for the power given to the armature, we get

$$n\,F_{pf} = \frac{33{,}000}{2\,\pi \times 746} \cdot E_a\,C_a = E_a\,C_a \times 7{\cdot}04.$$

Now, E_a, the E.M.F. generated by the rotating armature tends to send a current in the opposite direction through the circuit; it is therefore sometimes called the *counter*-E.M.F. of the motor. The faster the motor runs, and the stronger the magnetic field of the machine, the greater does, E_a, become, and the more does it oppose the flow of current through the motor. In a modern well-designed motor, E_a, will (when the motor is doing full work) be a little less (from 5 to 10 per cent.) than, E_M, the difference being the "lost volts" $= R_a\,C_a$—*i.e.*, volts lost by reason of internal resistance of conductors in the armature part of machine. Also, if the motor's field-magnets are shunt-wound, C_a, will be from 5 to 10 per cent. less than, C_M.

Alternate-current Motors.—Motors to work in circuits supplied with alternate currents are not yet (1889) really a practical success. This is one reason against the use of alternate current systems of distribution.

Continuous-current Motors.—Continuous currents are usually supplied under one of two standard conditions, either—

(1) At *Constant Potential*, as usual for lighting with glow-lamps; or,

(2) With *Constant Current*, as for arc lamps in series.

Motors which are to be put on a constant potential circuit will not do for insertion in an arc light circuit, and *vice versâ*. Neither must a motor intended to work at, say, 50 volts, be used on mains when the pressure is, say, 100 volts. If the potential of the supply is fixed, motors to run at any desired speed, and to do any required amount of work need to be designed for the purpose. Suppose, for example, the E.M.F. of the supply mains is 100 volts, and that the motor is required to do 2½ H.P. at a speed of 1,200 revolutions per minute.

Now 2½ H.P. is 1865 watts. Assume that the lost volts at full load will be but 5: then, $E_a = 95$ volts; hence, C_a, must be equal to $1865 \div 95 = 19{\cdot}6$ amperes. The motor must, therefore, be so designed that if run as a dynamo at 1200 revolutions per minute it will give an E.M.F. of 95

volts, and carry a current of 19·6 amperes. It is desirable that motors should run at fairly constant speed, independent of the load which they are driving. If the condition of supply be constant potential, then any motor which has a very small armature resistance, and whose field-magnet is powerful and excited to a constant degree, will run at a nearly constant speed. A good *shunt motor* answers this description, as the current through the shunt is a constant. A *series motor* will not answer, as the speed increases greatly when the load is diminished. A perfectly self-governed motor may be made by combining with the shunt winding an auxiliary demagnetising coil in series. For working in arc lighting circuits with constant current the differential winding is not so successful. In all motors having a constant field-magnetism the torque depends solely on the current through the armature, and the speed depends solely upon the E.M.F.

Management of Motors.—The practical hints given above for the management of dynamos are also applicable to motors, except that there is no need at the end of the run to raise the brushes.

Electrical Transmission of Power.—When power is to be transmitted electrically to a distance, the design of the motors must depend on the conditions of distribution; if this is to be at constant potential, shunt-wound motors or differential-compound motors will be found the best. But if the power is merely to be sent from one generating dynamo, through a single line to one motor, then it will be found simplest to use series-wound machines; for these, if of similar build, compensate each other very accurately, the speed of the motor remaining constant with all loads if the generator be run at a constant speed.

Economy of Transmission.—

If, E_G, be the E.M.F. developed in the armature of the generator (series-wound),

E_M, be the counter E.M.F. developed in that of the motor.

R_G, R_L, and R_M, be the resistances of the generator, line, and motor, respectively; then the current will be

$$C = \frac{E_G - E_M}{R_G + R_L + R_M}.$$

The H.P. (electrically measured) absorbed by the generator is $E_G\,C \div 746$, while that given out by the motor is

$E_M C \div 746$; hence the efficiency of the system, being the ratio of the latter to the former is equal to $E_M \div E_G$. By the fundamental principles of dynamos (see above) if the machines are of similar design and equally excited magnetically, their E.M.F.'s are proportional to their speeds; and the economy of transmission (supposing that there is no leakage) is given by the ratio of the speeds,

Or, $$= \frac{n_M}{n_G} = \frac{\text{Speed of motor}}{\text{Speed of generator}}.$$

If the machines are shunt-wound or compound-wound, or when there is leakage on the line, the currents through the two armatures will no longer be alike.

Writing, C_G, and, C_M, for the respective currents, we get as the ratio of electrical efficiency of transmission $E_M C_M \div E_G C_G$.

As an example, in recent experiments at Kriegstetten in Switzerland, using a conducting line of 9·23 ohms resistance, the observed values were,

$$E_G = 1231{\cdot}6;\ E_M = 988{\cdot}6;\ C_G = 14{\cdot}204;\ C_M = 14{\cdot}177.$$

The actual H.P. measured mechanically at the two stations showed a commercial efficiency of 74·7 per cent.

TRANSFORMERS.

(By Gisbert Kapp.)

Theoretical Considerations.

The two essential parts of an alternate current transformer are a closed magnetic circuit formed by a laminated soft iron core, and a closed electrical circuit consisting of a primary and a secondary coil. The two circuits interlace, and the coils are placed either upon each other or in short alternating sections, side by side, so as to enclose the same flow of magnetic lines. It is desirable to keep down the resistance of the magnetic circuit, but not at the expense of increasing the resistance of the electrical circuit. A low or short electrical resistance is of more importance than a low or short magnetic circuit or resistance. Transformers may be used as follows:—

1. *In Parallel*, when the primary terminals are joined with constant pressure conductors, and varying currents of nearly constant pressure are obtainable from the secondary terminals. The secondary of a "parallel transformer" may be open circuited, but must *never be* short circuited.

2. *In Series*, when the primary terminals are inserted into a constant current circuit, and a nearly constant current at varying pressures is obtainable from the secondary terminals. The secondary of a series transformer may be short circuited, but must *never be* open circuited.

Index to Symbols.

M_F for maximum *magnetic flux* through coils in C.G.S. units.

M_I ,, maximum *magnetic induction* or flow through one square centimetre of cross sectional area of core occupied by iron.

S_c ,, total cross *section* of iron *core* in square centimetres.

L ,, mean *length* of magnetic circuit in centimetres, including an allowance of 10 centimetres for each butt joint.

E_p E_s ,, maximum opposing E.M.F. in primary, and maximum induced E.M.F. in secondary respectively, in volts.

e_p e_s for mean terminal electrical pressure on primary and secondary respectively, in volts.

R_p R_s ,, *resistance* of *primary* and *secondary* circuits respectively, in ohms.

C_p C_s ,, maximum value of *primary* and *secondary current* respectively, in amperes.

C_{mp} C_{ms} ,, *mean* value of *primary* and *secondary current* respectively, in amperes.

t_p t_s ,, number of *turns* of *primary* and *secondary* respectively.

n ,, *number* of complete cycles per second.

M_P ,, magnetic permeability of the core.

E_f ,, maximum effective *Exciting-force* or magneto-motive-force in ampere-turns producing the flow of lines or magnetic flux, M_F.

R ,, resistance of magnet iron core.

$E_f = a \cdot t_w$ where $a =$ amperes and t_w turns of wire.

$$R = \frac{L}{S_c},$$

$$M_F = \frac{4\pi M_P E_f}{10 R}.$$

The permeability, M_P, varies according to the nature of the iron, and the induction, M_I, between 1000 and 2000. If the induction be less than 5000, the transformer becomes too heavy for its output; if it be more than 9000, there is difficulty in keeping the core cool. A fair average value is $M_I = 7000$; when, with good soft iron, $M_P = 1100$, and

$$E_f = 5 L$$

$$M_F = 7000 S_c.$$

It is generally assumed that the curve representing current or electro-motive force represents a simple sine function of the time, in which case the maximum value divided by $\sqrt{2}$ gives the mean value.

$$E_p = 2\pi n \mathbf{M}_F t_p 10^{-8}$$

$$E_s = 2\pi n \mathbf{M}_F t_s 10^{-8}$$

$$e_s = \cdot 71 E_s - R_s C_{ms}.$$

In a parallel transformer, the ratio, t_s/tp, is approximately equal to the ratio between primary and secondary pressure $= e_p/e_s$. In a series transformer, the ratio t_s/t_p is approximately equal to the inverse ratio between primary and secondary current $= C_s/C_p$. In order that a parallel transformer may be fairly self-regulating the loss of E.M.F. by ohmic resistance, $(E_s \div C_{ms})$ should at full output not exceed 1°/₀ of the mean induced E.M.F. Similarly, the loss of pressure in the primary should not exceed 1°/₀ of the pressure on the mains. The drop of pressure on the secondary terminals from no load to full load will then be limited to 2°/₀, and the energy wasted in copper-heat will also be limited to 2 °/₀ of the full output.

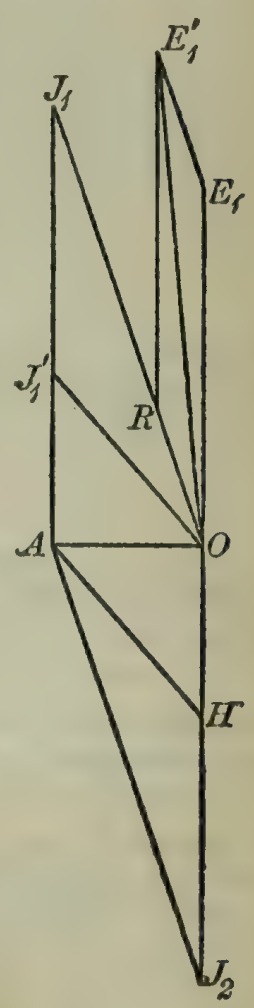
Induction.	Ergs per Cycle per Cubic c.m.	Rate in Watts per	
		Cubic d.m.	Cubic Foot.
3000	1200	12	340
4000	1600	16	450
5000	2300	23	650
6000	3000	30	850
7000	3700	37	1050
8000	4500	45	1280
9000	5500	55	1560
10000	7000	70	2000

In order that no heat may be generated in the copper on account of unequal current density or Foucault currents, the diameter of the wire should not exceed 250 mils. If a stouter conductor be required, it should be subdivided.

Notwithstanding the sub-division and insulation of the iron core, some heat is generated by magnetic hysteresis. The rate at which iron-heat is generated depends on the quality of the iron, and the total volume affected by magnetism, on the induction, and on the period of alternation. The preceding table gives the energy wasted in hysteresis with soft annealed wrought iron for $n = 100$.

The effect of hysteresis is not only to heat the core, but also to oppose its magnetisation, and in the latter respect may be expressed as so many ampere-turns acting in opposition to the exciting force of the primary, and in the same sense as that of the secondary current. Let in a parallel transformer, P_W, be the number of watts representing the rate at which energy is being transformed into heat by hysteresis, e_3 the mean E.M.F. induced in an imaginary third coil of, t_3, turns of such resistance that with a current, c_3 (maximum value C_3) an equal amount of energy shall be lost in this coil. then the maximum demagnetising force of this coil is

$$C_3\, t_3 = \frac{2\, P_W}{2\pi\, n\, M_F\, 10^{-8}}.$$



In the following it is supposed that the external circuit of the secondary coil contain only glow lamps, or other translating devices having no appreciable self-induction.

Let value, $C_3\, t_3$, in the diagram be represented by the length, O H, and represent the maximum demagnetising force of the secondary current, and the effective exciting force by the lines, H J_2, and O A, respectively, the lines being drawn to the same scale. The exciting force of the primary is then represented by O J_1, which is made equal and parallel to J_2 A. This gives the primary current and its position as compared with the secondary current. When the trans-

former is working at full output, the exciting force of the secondary is very many times larger than the effective exciting force, and consequently the phase of the primary current is nearly opposite that of the secondary current. As the load decreases, the point, J_1, approaches nearer to A, until at no load it reaches J'_1, the distance, $A J'_1$, being equal to O H. The length, $O J'_1$, represents the primary exciting force when the secondary is open circuited, and by dividing this by, $\sqrt{2}t_p$, we obtain the mean value of the primary current when no work is being done by the secondary. Let $O E_1$ in the same diagram represent the maximum E.M.F., E_p, which opposes the primary current, and O R, the maximum loss of pressure ($C_p R_p$) occasioned by the ohmic resistance of the primary, and make $E'_1 E$ equal and parallel to O R, then $O E'_1$ represents the maximum pressure on the primary terminals, and

$$e_p = \frac{O E'_1}{\sqrt{2}}$$

The angle α is the lag of the primary current behind the primary impressed E.M.F. The energy supplied or put in to the transformer in watts is

$$P_{WI} = e_p C_{mp} \cos \alpha.$$

The energy given out by the secondary is

$$P_{WO} = e_s C_{ms}.$$

and the efficiency is $\frac{P_{WO}}{P_{WI}} = \frac{e_s C_{ms}}{e_p C_{mp} \cos \alpha}$.

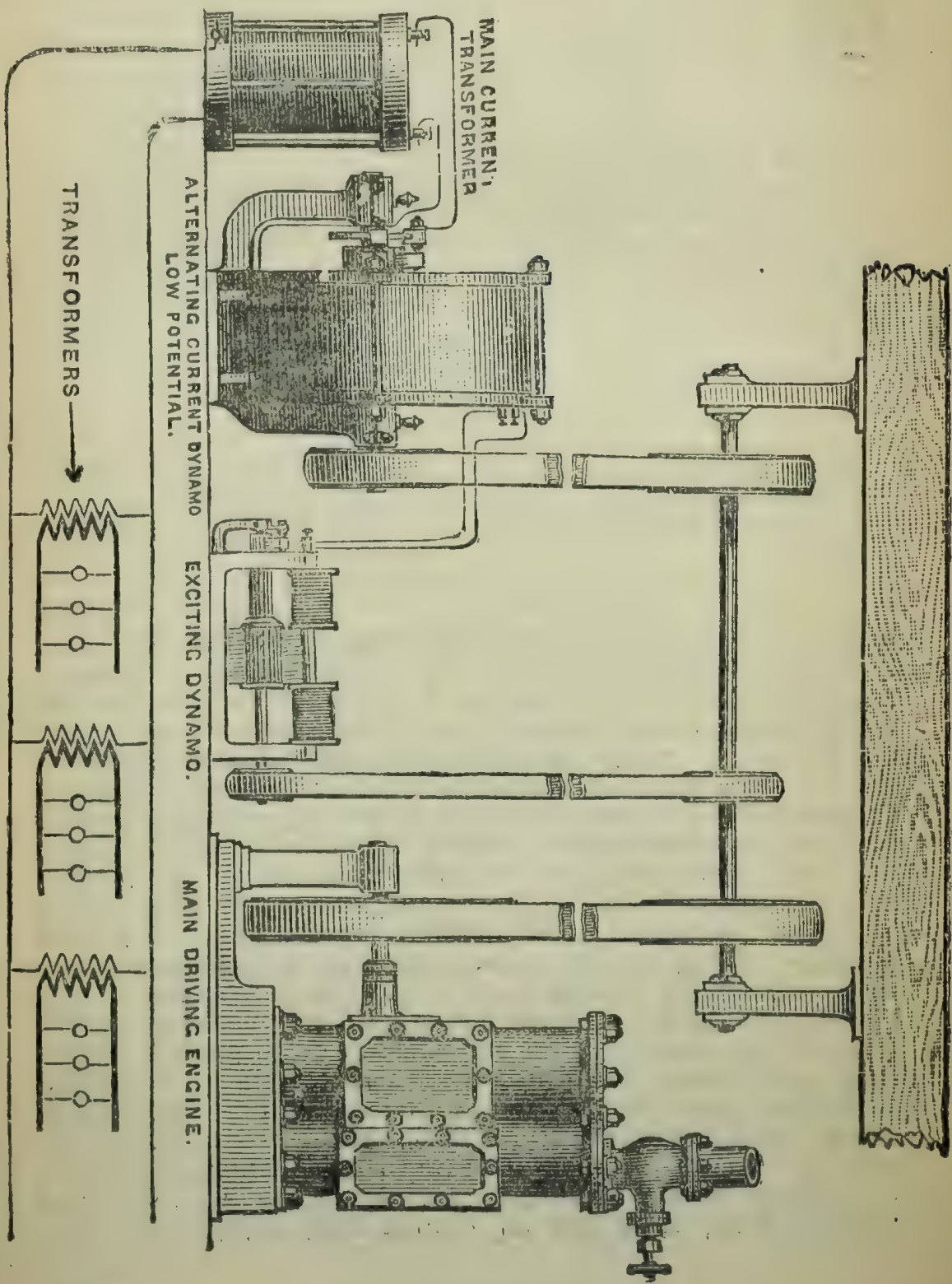
The efficiency of a good transformer at full output is about 96 per cent., and at one third output 90 per cent.

Practical Hints.

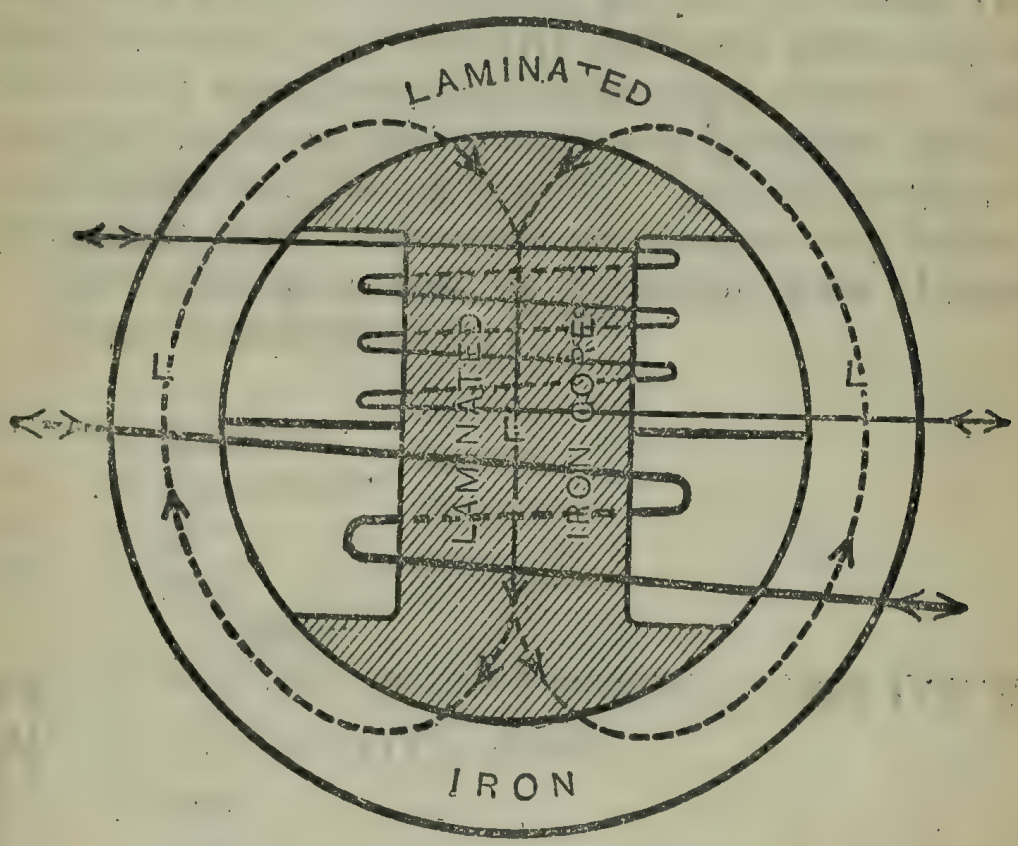
If the air has free access to the transformer, it is sufficient to provide a cooling surface of 20 square centimetres (3·1 sq. in.) for every watt lost in iron and copper heat. For outdoor work, the transformer must be put into a water-tight iron case, and should have a somewhat larger cooling surface. The case itself should also have at least an equal cooling surface to the transformer. The leads must be brought through the case by means of insulated stuffing-boxes. If the core of the transformer consists of iron wire, this should be single cotton covered;

if of iron plates they should be not more than 25 mils. (·63 m.m.) in thickness, and adjacent plates should be insulated from each other by varnish, paint, or thin varnished paper. About 25 per cent. of the space is lost in the insulation. The plates should be annealed after cutting or punching. To facilitate manufacture and repairs, the transformer should be so constructed that the coils and the core may be independently made and put together when finished. The primary and secondary coils should be separated by ebonite insulation, and successive layers of the primary should be insulated by wrappings of varnished paper or linen. The varnish should be shellac or copal dissolved in linseed oil. It is important to very thoroughly dry the transformers before using them. For this purpose the coils should be heated for many hours by means of a continuous current. When in use it is advisable to connect the framework and core of the transformer to earth. It should be put into a dry place, as far as possible from inflammable substances, and should not be accessible to unauthorised persons. The weight of transformers varies, according to the size and type, between 15 lbs., and 50 lbs., per horse power.

Kennedy's Alternating Current & Transformer System of Distribution.



In this system the generating dynamos are made of a comparatively low pressure, and the pressure is raised to 5,000 or 10,000 volts in the main distributing wires by one or more transformers, other transformers on the consumer's premises reduce the pressure from 5,000 or 10,000 to 50 or 100 volts, which is shown diagramatically by the foregoing figure.



RANKIN KENNEDY TRANSFORMER.

One form of transformer used in this system of distribution is shown in section in the above figure.

The dimensions here given are in Centimetres and the lettering is the same as in Kapp's notes on transformers, so that the formulæ given there may be applied.

$S_c = 10 \times 7{\cdot}5 = 70{\cdot}5$ c.m.

$\mathsf{L} = 60$ c.m., which includes 10 centimetres for each joint.

$\mathsf{R} = \frac{60}{70{\cdot}5} = 0{\cdot}85.$

$\mathsf{M}_P = 1000.$

$n = 100.$

$\mathsf{E}_f = 300.$

$\mathsf{M}_F = 442{,}506$ C.G.S. lines.

$\mathsf{M}_I =$ per c.m. of cross-section $= 6335$ C.G.S. lines.

$e_p = 800.$

$e_s = 40.$

$t_p = 400$ turns.

$t_s = 20$ turns.

Ratio of windings 20 to 1.

The core is made of charcoal iron plates insulated from each other by shellac and paper. The plates are No. 24 S.W.G. The outer shell is built of charcoal iron washers of the sam thickness, and also insulated from each other. The shell is bored out, slightly tapering from end to end, and the core is turned to fit it, so that the core with its coils may be withdrawn.

ELECTRIC LIGHTING.

Light.

Velocity of Light = 192,000 miles per second (nearly). Or, about 300,000 kilometres per second.

Composition of Sunlight.—

Violet = maximum chemical ray.
Indigo. Blue. Green.
Yellow = maximum light ray.
Orange.
Red = maximum heat ray.

Colours.

Primary.	Secondary.	Tertiary.
Red.	Orange.	Brown.
Yellow.	Purple.	Gray.
Blue.	Green.	Broken Green.

Contrasts of Colours.

Primary.	Secondary in contrast to Primary.	Tertiary in contrast to Primary.
Red.	Green.	Brown.
Yellow.	Purple.	Gray.
Blue.	Orange.	Broken Green.

Intensity of Illumination, or the quantity of light received on unit surface, is inversely as the square of its distance from the source. When the light falls obliquely the intensity is proportional to the cosine of the angle which the rays make with the normal to the surface.

Photometers measure the relative intensities of lights. In **Rumford's** they are compared by the shadows of an opaque rod thrown by the two lights compared on a white screen. When the shadows are of equal darkness,

$$\frac{i_1}{i_2} = \frac{d_1^2}{d_2^2}.$$

Where i_1 = intensity of one light at distance d_1
i_2 = ,, other ,, ,, d_2

In **Bunsen's** photometer a piece of bibulous paper with a grease spot on it is placed between the two lights, where the spot and the rest of the paper appear alike. Then, $\frac{i_1}{i_2} = \frac{d_1^2}{d_2^2}$. In **Ritchie's** two equal white surfaces are placed at an angle to receive the two lights, and their brightness compared. In Ayrton and Perry's **dispersion** photometer a concave lens is introduced in the path of the stronger light to reduce its power by dispersion to a known degree. In Sabine's **wedge and diaphragm** photometer the stronger light is reduced to a known degree by passing through a wedge of neutral tinted glass. It allows of the coloured rays being compared. In **Wheatstone's** photometer a revolving bead between the lights gives two images, which are of equal brightness, when $\frac{i_1}{i_2} = \frac{d_1^2}{d_2^2}$. Harcourt's table photometer gives accurate results by comparison with a standard pentane flame.

Joly's.—Two slabs of wax paraffin, or translucent glass, each about 3 in. × 2 in. × ½ in., or 50 × 20 × 11 mm., are joined on two of their larger faces by Canada balsam; a sheet of paper or silver foil being interposed, and the external faces ground smooth. This compound slab is placed between the two lights, with the plane of the joint at right angles to their line. The observer looks at the edge of the joint, and shifts the slab until the paraffin on both sides of it is equally illuminated. A check is got by reversing the slab and taking the mean.

INCANDESCENCE.—Temperature at which solid bodies begin to glow—about 1,000° Fah. The more refrangible rays appear as the temperature rises.

At 1,000° F.	we have the red rays	(977° F., *Draper*).	
,, 1,200	,, ,, orange ,,	(1,210 ,, ,,).	
,, 1,300	,, ,, yellow ,,	(1,325 ,, ,,).	
,, 1,500	,, ,, blue ,,	(1,440 ,, ,,).	
,, 1,700	,, ,, indigo ,,		
,, 2,000	,, ,, violet ,,	(2,130 all colours—*i.e.*, white light, *Draper*).	

The intensity of the light emitted increases more rapidly than the temperature. Thus, a platinum wire at 2,600° F. emits forty times more light than at 1,900°.

ANALYSIS OF LIGHTS (*Tyndall*).—

	Visible Rays.		Invisible Rays.
Gas, . . .	1	to	24
Incandescent wire, .	1	to	23
The Arc, . . .	1	to	9

Matching Colours.—Arc lights are richer in the more refrangible rays than gas, oil, or incandescence, and show greens and blues more vividly. All colours, except certain drabs and aniline browns, can be matched by the arc light. For this the carbons should be pure and free from sodium and calcium, the arc clear and open. Incandescent lamps contain 20 per cent. more orange rays than daylight (*Sabine*), and hence are unsuited for matching. The magnesium light resembles daylight most of all; the lime light comes between gas and the arc.

CHEMICAL EFFECT OF THE ARC LIGHT.—Fizeau and Foucault estimated it at one-fourth that of sunlight at noon in August.

Photography.—Crompton found that in the Woodbury process, where the sensitised gelatine plates require great actinic power, the yellow and citron band rays appear the most effective.

TEMPERATURE OF THE VOLTAIC ARC.—It varies with the strength of current and size of the carbons, being higher with thinner carbons and stronger currents. Rosetti made the positive carbon 3,200° C.; the negative 2,500° C. Dewar gives 6,000° C. Temperature of the sun 9,000° C. (*Rosetti*), 3,000° C. (*Siemens*); of the oxyhydrogen light 2,000° C.

TEMPERATURE OF THE INCANDESCENT LAMP.—Swan's filament 1,900° C. (*Dewar*). Platinum melts at 1,900° C.

HEATING EFFECT OF LIGHTS.—(*Ferd.*)

Light of 100 Candle-power.	Products per Hour.	
	Heat in Calories.	Carbonic Acid in cubic metres.
Electric arc, ...	57 to 158	0*
,, incandescence, .	290 to 536	0
Gas, Siemens' burner, . .	1500	—
,, Argand ,, . .	4860	0·46
,, Manchester ,, . .	12150	1·14
Petroleum, large round burner,	3360	0·44
Colza oil, carcel, ,,	4200	0·61
,, student's lamp, .	6800	1·00
Candles, paraffine, . . .	9200	1·22
,, wax and spermaceti,	7960	1·17
,, stearine, . . .	8940	1·30
,, tallow, . . .	9700	1·45

* With some carbons acid is given off.

According to Morin, a burner consuming 5 cubic feet of gas per minute gives off 48½

calories per minute, or 2,910 per hour. It follows that incandescent lamps yield from $\frac{1}{5}$ to $\frac{1}{10}$ the heat of equivalent gas-jets; arcs from $\frac{1}{20}$ to $\frac{1}{50}$.

Absorption of the light by water vapour reduces the lighting power of arc proportionately more than incandescence lamps in misty weather.

Absorption by Globes.—The light cut off by globes is for ordinary glass 10 per cent., light ground glass 30 per cent., heavy ground 45 to 50 per cent., and strong opal 50 to 60 per cent.

Incandescence Lamps.—According to the Paris Exhibition tests, if the horizontal intensity in front of an Edison lamp is 1, the mean intensity all round is 0·98. The horizontal intensity at an angle of 45° to the front is 1·33. The mean spherical intensity of a Maxim lamp is 0·74, that of a Swan or Lane-Fox lamp is 0·58.

By the same tests the effective light of incandescence lamps for a mean spherical intensity of 1·20 carcels was made from 12 to 13 carcels per arc H.P., or 10 carcels per H.P. expended. Electric candles gave 40, and arc lamps 100 carcels per H.P. expended. The economic values of arc, candle, and incandescence lamps were, therefore, as 7 : 3 : 1. The stronger the light the better was the economic result. (See p. 389.)

Effective Area Lighted.—In rooms about 10 ft. high, a 16 c.p. incandescent lamp, placed about 7 ft. from the floor, effectively lights 100 square feet of horizontal tract about the lamp as a centre.

For electro-motive forces not far from those at which an incandescent lamp is intended to

be used (*e.g.*, an Edison 16 c.p. lamp at 100 volts):—

1. *Average life* varies inversely as the 25th power of the E.M.F.

2. *Efficiency*, or c.p. per H.P., varies as the 4th power of the E.M.F.

3. *Candle power* varies as the 6th power of the current, and therefore as the 6th power of the E.M.F., seeing that the res. alters very little after the lamp has reached a fair incandescence. This law holds to the point of disintegration.
—*Preece.*

4. From the above (1, 2, 3) the *life* varies inversely as the 6·25th power of the efficiency, and also inversely as the 4·25th power of the candle-power.

5. Independently of the price of a lamp or cost of electrical energy, a lamp should be run at such a pressure that lampage (or cost of c.p. as far as the lamp itself is concerned) is about 18°/₀ of the total cost.—(*J. A. Fleming, D.Sc., Physical Soc. Proc.*, March 14, 1885; or *Electrician*, 28/3/85.)

Coated Carbons.—Metal-plated or Mignon and Rouart's enamelled carbons last longer and crater less than bare ones. Nickel plating prolongs their duration from 50 to 60 per cent.; copper plating from 30 to 40 per cent.

Resistance of the Arc.—This varies with the "back E.M.F." From the E.M.F. between the carbons, E, and the current passing in the arc, C, it can be calculated.

According to Dr. O. Frolich's empirical formulæ:—

(1.) The E.M.F. of the arc $E = a + b\,L$; where L = length of the arc, and a, b, are numbers.

Numerically, when E is in volts, and L in millimetres $E = 39 + 1{\cdot}8\,L$.

(2.) The apparent resistance of the arc

$$\therefore\ R = \frac{E}{C} = \frac{a}{C} + b\frac{L}{C}$$

where C is the current

$$\therefore R = \frac{39}{C} + 1{\cdot}8\frac{L}{C}.$$

CARBONS.—Carré's carbons are composed of pure powdered coke 15 parts, calcined lampblack 5 parts, special syrup 7 to 8 parts, mixed with water moulded and dried in a crucible. Gaudoin's carbons, made from the residue of tar or bitumen, burn very steadily, and, according to Fontaine, wear longer than those of Carré or Achereau. Retort carbons last longest, but are apt to flicker and spark.

WEAR AND TEAR OF CARBONS.—With continuous currents the + wastes twice as fast as the — carbon, and a crater is formed. With alternating currents, the upper wastes 8 per cent. faster than the lower, if carbons vertical; but at the same rate if horizontal. To use the crater best as a reflector, the axis of the — carbon should be in the same vertical plane as the front of the + carbon. If too thin, carbons give a brighter light, but waste sooner; if too thick, they are apt to crater. Siemens' graphite cored carbons are less apt.

WEAR OF CARBONS.—Fontaine gives the following:—

	Size.	Turns of Generator per min.	Wear per hour.		Mean wear.	Light.
			—	+		
	mm. sq		mm.	mm.	mm.	
Retort carbon,	9	800	19	36	63	irregular, sparkling.
" "	9	920	23	48	63	
Achereau "	10	800	20	60	85	white, good, fairly regular.
" "	10	920	30	60		
Carré "	10·4	800	18	60	92	slight, sparkling, not so good.
" "	10·4	920	26	80		
Gaudoin "	11·3	800	20	38	73	very regular, no sparks, and little cinder.
" "	11·3	920	38	50		

TESTS OF INCANDESCENT LAMPS (*Jamieson*).

For details see *Journal Soc Tel. Engs.*, Vol. XI., p. 164.

LAMP. Normal c p.	Res. Cold by Bridge $= r$.	Res. Hot Ohms $= R = \frac{E}{C}$.	E.M.F. Volts $= E$.	Current in Amperes $= C$.	Candle-power $=$ c.p. Horizontal.	No. of Candles per H.P. $= \frac{\text{c.p.} \times 746}{E \times C}$	No. of Lamps per H.P. $\frac{746}{E \times C}$	Watt's per Lamp $E \times C$.	Watt's per Candle $\frac{E \times C}{\text{c p.}}$
Swan, 20 c.p. .	66	33	40·14	1·22	8·5	130	15·27	49	5 8
,, ,, .	,,	32	47·6	1·49	21·6	225	10·5	71	3·3
,, ,, .	,,	31·1	51·64	1·67	34	293	8 6	86	2·5
B. E. Coy., .	158	76·5	61·4	·80	9·8	148	15·2	49	5·0
,, .	,,	71	71	1·0	30	313	10·4	71	2·4
Edison B, 8 c.p.	115	61	51·9	0·85	8·2	138	16 9	37	4·5
,, ,, ,,	,,	59 2	56·2	0·948	21·3	298	14	53	2·5
,, A, 16 ,,	250	153	98	0·64	16	190	12	62·7	3·9
Lane-Fox, 20 ,,	188	98	66	0·673	8·7	146	16·8	44·4	5·1
Maxim, ,, ,,	73	39·4	44 2	1·12	7·1	107	15·0	49·5	7·0
,, ,, ,,	,,	39·1	48·9	1·25	14·6	178	12·2	61	4·2
,, ,, ,,	,,	38 2	52·7	1·38	24·3	249	10·3	72·7	3·0
Gatehouse ,, ,,	88	46·2	60	1·3	20	191	9·6	78	3·9
Pilsen Coy. (Dec. 1883), .	78	38·4	43	1·12	20	310	15·5	48·2	2·4
Crookes, . .	119	66·7	70·7	1·06	21	209	10·	75	3·6

RULES AND REGULATIONS

For the Prevention of Fire Risks arising from Electric Lighting.

Issued April, 1888, by the Society of Telegraph-Engineers and Electricians.

Difficulties, Dangers, and Safety.

Chief Difficulties.—The chief difficulties which beset the electrical engineer are internal and invisible, and they can only be effectually guarded against by testing with special apparatus and electric currents; they arise from leakage and from bad connections and joints, which lead to waste of energy and the production of heat to a dangerous extent.

Moisture Danger.—The necessity for guarding against the presence of moisture, which leads to loss of current and to the destruction of the conductors and apparatus by corrosion and otherwise, cannot be too strongly urged.

Earth Danger.—Injudicious connections of any part of the circuit with the "earth" tend to magnify every other source of difficulty and danger.

Ignorance and Injudicious Economy.—Many of the dangers in the application of electricity arise from ignorance and inexperience on the part of those who supply and fit up inadequate

plant, and frequently from injudicious economy on the part of the user.

Safety in Consulting Experienced Engineers.—The greatest element of safety is, therefore, the employment of skilled and experienced electrical engineers to specify the method in which the work is to be done and the quality of the materials to be employed, and to supervise the execution of the work.

Conductors.

1. *Sectional Area.*—Conductors must have a sectional area and conductivity so proportioned to the work they have to do that, if double the current proposed is sent through them, the temperature of such conductors shall not exceed 150° F.

2. *Accessibility.*—The conductors, or their casings, should be placed in sight if possible; and they should always be as accessible as circumstances will permit.

3. *Insulating.*—Within buildings they should all be insulated; and this rule applies equally to all conductors and parts of fittings which may have to be handled.

4. *Maximum Temperature.*—Whatever insulating material is employed, it should not soften until a temperature of 170° F. has been reached, and in all cases the material must be damp-proof.

5. *Casings.*—When leads pass through roofs, floors, walls, or partitions, and where they cross

or are liable to touch metallic substances, such as bell wires, iron girders, or pipes, they should be thoroughly protected by suitable additional covering; and where they are liable to abrasion from any cause, or to the depredations of rats or mice, they should be encased in some suitable hard material.

6. *Portable Fittings.*—In the case of portable fittings with which flexible leads are used, special precautions must be taken.

7. *Distance Apart.*—Conductors should be kept as far apart as circumstances will permit, the spacing between them being governed by their potential difference.

8. *Inflammable Structures.*—When conductors are carried in very inflammable structures, precautions should be taken to isolate them therefrom.

9. *Metallic Armour.*—Conductors which are protected on the outside by lead, or metallic armour of any kind, require the greatest care in fixing, on account of the large conducting surface which would become connected to the core in the event of metallic contact between them.

10. *Fire or Water.*—In cases where conductors pass into a building, from one building to another, or from one room to another, precautions should be taken to prevent the possibility of fire or water passing along the course of the conductors.

11. *Joints.*—All joints must be mechanically and electrically perfect, to prevent heat being

generated at these points. When soldering fluids are used in making joints, the latter should be carefully washed and dried before insulation is applied.

12. *Gas and Water Pipes.*—Under all circumstances complete metallic circuits must be employed. Gas and water pipes must never form part of the circuit, as their joints are rarely electrically good and therefore become a source of danger.

13. *Overhead Conductors.*—Overhead conductors, whether passing over or attached to buildings, must be insulated at their points of support. Precautions must be taken to obviate all risk of short-circuiting where they are likely to touch a building or other overhead conductors and wires, either by their own fall or by being fallen upon by other conductors.

14. *Lightning Protector.*—In the case of overhead wires, every main should have a lightning protector at each point where it enters or branches into a building.

15. *Metal Fastenings.*—Metal fastenings for fixing conductors should be avoided; but, when unavoidable, some additional covering should protect the couductor from mechanical injury at such fixing points.

16. *Insulation Resistance.*—The insulation of a system of distribution should be such that the greatest leakage from any conductor to earth (and, in case of parallel working, from one conductor to the other, when all branches are switched on, but the lamps, motors, &c., re-

moved), does not exceed *one five-thousandth part* ($\frac{1}{5000}$) of the *total current* intended for the supply of the said lamps, motors, &c.; the test being made at the usual working electro-motive force.

17. *Colouring* (+) *Leads.*—It will often be found a great convenience and assistance in the prevention of accidents if the positive lead be coloured differently to the negative, or made otherwise distinguishable.

Switches.

18. *Construction and Action.*—Every switch or commutator should be of such construction as to comply with the following condition, namely:—That, when the handle is moved or turned to and from the positions of "on" and "off," it is impossible for it to remain in any intermediate position, or to permit of a permanent arc, or heating.

19. *Insulated Handles.*—The handles of every switch must be completely insulated from the circuit.

20. *Main Switches—Position of.*—The main switches of a building should be placed as near as possible to the point of entrance of the conductors, or to the generators of the current if they are within the building itself. Switches should be provided on both leads.

21. *Switch Boards.*—Switch boards should bear clear instructions for their use by the inexperienced.

Electrical Fittings Generally.

22. *Bases.*—Switches, commutators, resistances, bare connections, lamps, &c., must be mounted on incombustible bases. Cut-outs mounted on bases of wood rendered uninflammable are admissible. Vulcanite bases are undesirable in damp situations. The cracking of porcelain and earthenware fittings is a source of danger which can be avoided by precautions in fixing.

Cut-outs.

23. *Imperative use of.*—All circuits should be protected with cut-outs; and all leads from the mains, or small conductors from larger ones, must be fitted with cut-outs at their branching points.

24. *Situation.*—Where fusible cut-outs are used, the section should be so situated within its frame that the fused metal cannot fall where it may cause a "short circuit" or an ignition.

25. *For* (+) *and* (−) *Mains.*—For all main conductors a cut-out should be provided for both the "flow" and "return;" and the two fusible sections must not be in the same compartment.

26. *For Portable Fittings.*—The flexible leads of portable fittings must in all cases be protected by cut-outs at their fixed points of connection.

Arc Lamps.

27. *Lanterns and Globes.*—Arc lamps must always be guarded by lanterns or netted globes,

so as to prevent danger from ascending sparks and from falling glass and incandescent pieces of carbon.

28. *Insulation of Parts.*—All parts of the lamps and lanterns which are liable to be handled (except by the persons employed to trim them) should be insulated.

The Dynamo.

29. *Insulation, Situation, &c.*—The armatures and field-magnet coils should be thoroughly insulated. Dynamos should always be fixed in dry places, and they must not be exposed to dust flyings or other industrial waste products carried in suspension in the air. They should not be permitted in the working rooms of mills, where the liability to such dangers exists, or where any inflammable manufactures are carried on or inflammable materials are stored.

30. *Motors.*—Motors should be subject to the same conditions; but when it is necessary to use them in positions such as those above referred to, they must be securely cased in, such cases having a non-combustible lining.

Batteries.

31. *Insulation.*—Both primary and secondary batteries should be placed and used under the same precautions as prescribed for dynamos; and the room in which they are placed should be well ventilated. The batteries themselves must be well insulated.

Transformers.

32. *Position.*—When these are used to transform either direct or alternating currents of high electro-motive force—that is, from or to an electro-motive force of, say, 200 volts—they, together with their switches and cut-outs, must be placed in a fire- and moisture-proof structure—preferably outside the building for which they are required. No part of such apparatus should be accessible except to the person in charge of their maintenance.

33. *Insulation.*—In all cases conductors conveying currents of high electro-motive force inside buildings must be specially and exceptionally insulated, cased in, and the casing made fire-proof.

34. *Distance apart of* (+) *and* (−) *Terminals.*—The positive and negative terminals connected to such conductors should not be permitted to be nearer each other than 12 inches.

35. *Heating.*—Transformers which, under normal conditions of load, heat above 150° F., should not be permitted to remain in use.

36. *Contact between Primary and Secondary.*—Transformers should be so constructed that under no circumstances whatever should a contact between the primary and secondary coils lead the high E.M.F. into the building.

Maintenance.

37. *Testing.*—The value of frequently testing and inspecting the apparatus and circuits cannot

be too strongly urged as a precaution against fire. Records should be kept of all tests, so that any gradual deterioration of the system may be detected.

38. *Cleanliness.*—Cleanliness of all parts of the apparatus and fittings is essential to good maintenance.

39. *Repairs.*—No repairs or alterations must be made when the current is "on."

General.—All the above rules, for the reduction to a minimum of the risks from fire, are also applicable in principle to installations of electricity for other uses than that of lighting; they also include precautions necessary to avoid risk of injury to persons, whether the conductors and apparatus are situated inside or outside a building.

(Signed) F. H. WEBB, *Secretary.*

4 THE SANCTUARY,
WESTMINSTER, *April*, 1888.

USEFUL INFORMATION REGARDING THE GAS COMPANIES OF GREAT BRITAIN AND IRELAND IN THE PRINCIPAL TOWNS, WHERE GAS COSTS 5/ OR LESS PER 1000 CUBIC FEET.

NAME OF TOWN.	Population in District supplied.	Annual Sale of Gas in 1000's cubic ft.	Illuminating Power Standard Candles per s cb. ft. per hour.	Price per 1000 cubic ft.	Number of Public Lamps.	Price paid for Public Lamps.	Dividend.
Aberdeen, . .	100,000	240,000	27 to 28*	4/ less dis.	2,526	city 3/6, and suburbs 4/	Redeeming annuities of £2000 to £3000 to original shareholders in old Gas Co.
Belfast, . . .	230,000	614,000	17½	3/2 less dis.	4,300	60/ each ⅜ an.	Corporation.
Birmingham, .	1,000,000	2,716,568	17¼	2/3 to 2/9 less 5 °/₀	10,000	2/3 less 5 °/₀	Corporation.
Bolton, ...	150,000	489,149	18½	2/8 to 3/5	3,033	2/8	Corporation
Bristol, . . .	250,000	980,000	17	2/4 to 2/9	4,800	2/4 less 5 °/₀	10
Dublin, . . .	360,000	...	16	3/11	...	...	7 & 10
Dundee, . . .	160,000	...	26	3/4	4,300	3/4	Corporation.
Edinburgh Gas Co., Ld., . .	170,000	638,830	28	3/8	8,000	3/4	10
Do., Leith and District, . .	129,000	285,170	27	3/8	1,401	3/5	8
Glasgow, . . .	750,000	1,807,851	27	2/8	...	13/8 per single jet	Corporation.
Leeds, ...	320,000	1,426,000	20	1/10, dis 2½ °/₀	7,000	6/6 each	Corporation.

* For other towns see Gas and Water Co.'s Directory and Gas-Works Statistics, by Charles W. Hastings. London, 1884.

USEFUL INFORMATION REGARDING THE GAS COMPANIES OF GREAT BRITAIN AND IRELAND—*Continued.*

NAME OF TOWN.	Population in District supplied.	Annual Sale of Gas in 1000's cubic ft.	Illuminating Power Standard Candles per s. cb. ft. per hour.	Price per 1000 cubic feet.	Number of Public Lamps.	Price paid for Public Lamps.	Dividend.
Liverpool, . .	750,000	...	21½	2/9	16,021	...	7 & 10
London, The Gas-Light and Coke Co., . .	...	14,636,909	16 com'n 20 cannel	3/ common 3/11 cannel	43,832	2/8 com'n, 3/6 cannel	11
Do., The South Metropolitan Co., ...	...	3,936,529	16	2/8	14,270	2/8 less dis.	12
Do., The Commercial Co., .	...	1,565,600	17	2/8	4,921	76/ each	9¾ & 12¾
Do., Crystal Palace District Co., . .	...	486,627	14	3/	2,044	3/1 less 5 °/₀	6, 7, 10
Do., Lea Bridge District Co., .	...	46,534	14	5/	370	...	7 & 10
Manchester, .	500,000	...	19¾	2/8 to 3/2	...	Free	Corpor.
Newcastle-on-Tyne, . . .	200,000	1,040,000	16	1/10½	6,087	1/ per lamp ℔ week, less 10 °/₀ dis.	9
Nottingham, .	250,000	...	18½	2/4 to 2/6	...	2/4	Corpor.
Oldham, . . .	160,000	580,994	18½	2/7 to 2/10 outside 2/9 borough 3/	3,081	2/6¼	,,
Salford, . . .	280,000	665,908	21	3/, 3/1, 3/7, 4/	6,240	3/	...
Sheffield, . . .	320,000	...	18	2/ to 2/4	4,900	2/	10

Useful Information regarding the Gas Companies of Great Britain and Ireland.
Small Towns where Gas costs more than 6/ per 1000 Cubic Feet.

Name of Town.	Population in District supplied.	Annual Make in 1000's cubic feet.	Illuminating Power in Standard Candles per s. cb. ft. per hour.	Price per 1000 cubic feet.	Number of Public Lamps.	Price paid for Public Lamps.	Dividend.
Aberlour, ...	600	190	...	13/	...	...	...
Banchory, ...	983	694	33	10/	19	7/6	5
Boughton Blean, . .	1,661	666	...	7/	...	...	5
Castletown (Isle of Man),	2,300	4,700	18	6/9 less dis.	...	...	...
Cawood, ...	1,147	...	16	7/	28	£48, 1st Oct. to 1st April	3½
Colyton, ...	2,480	...	...	7/6	...	...	...
Croston, ...	1,518	800	...	7/6	...	...	3½
Debenham, ...	1,349	580	...	10/*	...	60/ each	...
Dufftown, ...	1,252	700	28	12/6	...	...	5
Easter Buckie, . . .	2,500	960	23	9/2 less dis.	...	...	5
Ellon, ...	900	234	...	13/9	...	...	...
Fortrose, ...	914	120	25	14/	...	26/ each	...
Golspie, ...	1,100	650	30	10/	...	...	...
Inveraray, ...	935	1,200	30	10/	22	10/	10
Old Meldrum, . . .	1,492	...	...	10/	...	...	...
Roscommon, ...	2,619	1,102	19½	9/2	...	£30	...
Sedburgh, ...	1,983	1,500	...	7/6	...	20/ each	...
Wendover, ...	2,033	...	...	7/1	...	36/ ,,	5
Wenlock, ...	2,531	...	...	7/6	...	42/ ,,	4
Shefford, ...	1,073	1,698	20	6/8	20	35/ ,,	6

In England there are over 99 towns charging from 5/6 to 6/8.
In Scotland ,, 40 ,, ,, ,, 6/0 to 10/.
In Ireland there are 28 towns charging from 6/ to 10/.
In Wales 5 towns charge 6/8; and all others under.

For other towns, see the Gas & Water Co.'s Directory and Gas-Works Statistics, by Charles W. Hastings. London, 1884.

* The highest priced gas in England.

MISCELLANEOUS.

Frictional Series.—The substances higher in the list become + when rubbed with any of those following, which becomes – : Fur, wool, ivory, glass, silk, metals, sulphur, india-rubber, guttapercha, collodion.

Contact Series OF METALS IN AIR.—Each metal is + in contact with all following:—Sodium, magnesium, zinc, lead, tin, iron, copper, silver, gold, platinum, graphite. Contact E.M.F. in volts:—For zinc-lead, ·210; lead-tin, ·069; tin-iron, ·313; iron copper, ·146: copper-platinum, ·238; platinum-carbon, ·113.—(*Ayrton and Perry*).

SPECIFIC INDUCTIVE CAPACITIES.

Substance.	Specific Inductive Capacity.	Authority.
Vacuum, air at about 0·001 millimetre pressure, .	0·94 about	Ayrton.
Vacuum, air at about 5 millimetres' pressure, .	0·9985	Ayrton.
	0·99941	Boltzmann.
Hydrogen at about 760 millimetres' pressure, .	0·9997	Boltzmann.
	0·9998	Ayrton.
Air at about 760 millimetres' pressure, . .	1	Taken as the standard.
Carbonic Dioxide at about 760 millimetres' pressure,	1·000356	Boltzmann.
	1·0008	Ayrton.
Olefiant Gas at about 760 millimetres' pressure, .	1·000722	Boltzmann.
Sulphur Dioxide at about 760 millimetres' pressure,	1·0037	Ayrton.
Paraffin Wax, Clear, . .	1·92	Schiller.
	1·96	Wullner.
	1·977	Gibson and Barclay.
	2·32	Boltzmann.
Paraffin Wax, Milky, . .	2·47	Schiller.
India-rubber, Pure, . . .	2·34	Schiller.
,, ,, Vulcanised,	2 94	Schiller.
Resin, ...	2·55	Boltzmann.
Ebonite, ...	2·56	Wullner.
	2·76	Schiller.
	3·15	Boltzmann.
Sulphur, ...	2·88 to 3·21	Wullner.
	3·84	Boltzmann.
Shellac, ...	2·95 to 3·73	Wullner.
Guttapercha, ...	4·2	
Mica, ...	5	
Flint Glass, Very light, .	6·57	J. Hopkinson.
,, ,, Light, . . .	6·85	
,, ,, Dense, . . .	7·4	
,, ,, Double extra dense, . .	10·1	

Conducting Series.—The substances are arranged in the order of their conductivity (see p. 194):—

Silver, . . .	Good conductors.
Copper, . .	
Gold, . . .	
Zinc, . . .	
Platinum, . .	
Iron, . . .	
Tin, . . .	
Lead, . . .	
Mercury, . .	
Charcoal and coke,	Sometimes classed as conductors, sometimes as semi-conductors.
Acids, . . .	
Saline solution, .	
Sea-water, . .	
Water, . . .	
The body, . .	Partial or semi-conductors.
Cotton, . . .	
Drywood, . .	
Marble, . .	
Paper, . . .	
Oils, . . .	Non-conductors or insulators.
Porcelain, . .	
Wool, . . .	
Silk, . . .	
Sealing-wax, . .	
Sulphur, . .	
Resin, . . .	
Guttapercha, .	
India-rubber, .	
Shellac, . .	
Paraffin wax, . .	
Ebonite, . .	
Glass, . . .	Varies much in power with the quality.
Dry air, . .	Rarefied air stands higher on the list according to its pressure.

Thermo-electric Scale. — With respect to lead, at a mean temperature of 20° C. (*Matthiessen*). The E.M.F.'s are in micro-volts per degree centigrade :—

Bismuth of commerce in Wire,	+ 97·0	Antimony, pure, in wire,	— 3·8
,, pure ,,	+ 89·0	Silver, ,,	— 3·0
,, crystallised along axis,	+ 65·0	Zinc, ,,	— 3·7
,, ,, normal to axis,	+ 45·0	Copper, galvano-plastic,	— 3·8
Cobalt,	+ 22·0	Antimony of commerce in wire,	— 6·0
German Silver,	+ 11·75	Arsenic,	— 13·56
Mercury,	+ 0·418	Iron, piano wire,	— 17·50
Lead,	0·	Antimony, crystallised along axis,	— 22·60
Tin,	— 0·1	,, normal to axis,	— 26·40
Copper of Commerce,	— 0·1	Phosphorus (red),	— 29·70
Platinum,	— 0·9	Tellurium,	— 502·00
Gold,	— 1·2	Selenium,	— 807·00

Thermo-piles — *Gaugain's standard.* — One joint at 0° C., the other at 100° C.

$$E = \frac{1}{182 \cdot 6} \text{ volts.}$$

Noë's.—German silver, alloy of antimony and zinc. Each element gives an E.M.F. of $\frac{1}{16}$ volt, and a resistance of $\frac{1}{40}$ ohm. Twenty elements in series have ∴ an E.M.F. of 1·25 volts and a resistance of 0·5 ohm.

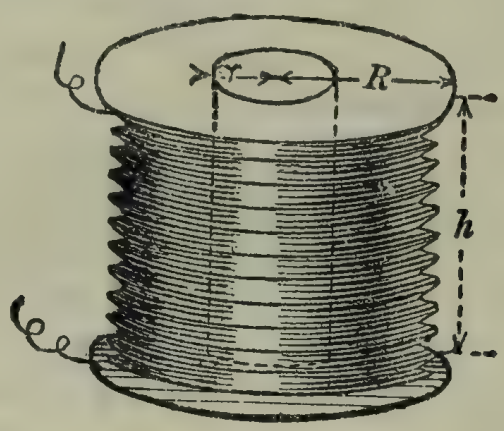
Clamond's.—Alloy of bismuth, and antimony —special solder. Sixty elements (heated with coke) give 1·09 volts; resistance, ·155 ohms.

The hot joints of thermo-piles should not be allowed to cool, otherwise they may sever.

Sparking Distance.—Riess found the sparking distance increase in a ratio a little exceeding that of the difference of potentials. De la Rue found that a chloride of silver battery, giving an E.M.F. of 1,000 volts, produced a spark ·0127 centimetres (about $\frac{1}{200}$ inch) long; 5,880 cells gave one $\frac{1}{17}$ inch long; 11,000 cells one 1·59 centimetres ($\frac{2}{3}$ inch) long. Carey Foster found, with sparks from a frictional machine between small brass balls, that $V = 102\ L + 7 \cdot 07$, where V is the difference of potential required to give a spark L centimetres in length. The rule is accurate for sparks over a millimetre and under a centimetre in length.

Filling a Circular Bobbin with Round Wire.—(See also p. 322.)—*Jamieson.*

Let r = radius of bobbin core.
R = ,, ,, outside.
d = diameter of wire outside insulating covering.
h = height or length of bobbin between inside of flanges.



L = length of wire on bobbin (with very close winding).
n = number of turns of wire in a section.
N = ,, ,, on bobbin.

N.B.—*The signs r, R, d, h, and L must be taken in the same unit, feet, inches, or centimetres.*

Then

$$L = \frac{\pi h}{d^2}(R^2 - r^2)$$

$$n = \frac{R - r}{d}$$

$$N = \left(\frac{R - r}{d^2}\right) h.$$

EXAMPLE.—Suppose that we have a bobbin of the following dimensions:—$r = 1''$, $R = 2''$, $h = 6''$, and that we wish to wind upon it No. 14 S.W.G. wire (0·08″) covered with double lapped very fine cotton which measures outside the covering $0{\cdot}1'' = d$; what length of wire, L, will the bobbin hold with close tight winding.

$$L = \frac{\pi h}{d^2}(R^2 - r^2)$$

$$= \frac{\pi \times 6''}{1^2}(2^2 - 1^2)$$

$$= \frac{3{\cdot}1416 \times 6}{{\cdot}01}(4 - 1)$$

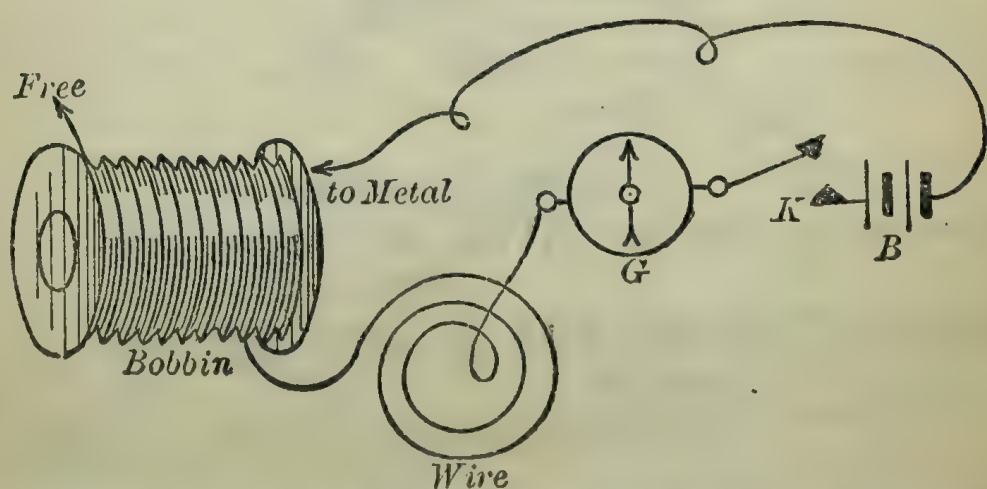
$$= \mathbf{5654{\cdot}88} \text{ inches} = \mathbf{471{\cdot}24} \text{ feet.}$$

And,

$$N = \left(\frac{R - r}{d^2}\right) h$$

$$= \frac{2 - 1}{{\cdot}01} \times 6 = 600 \text{ turns.}$$

Double cotton covered wire, for all practical purposes, may be taken as increasing the diameter of a wire by ·02 inch.

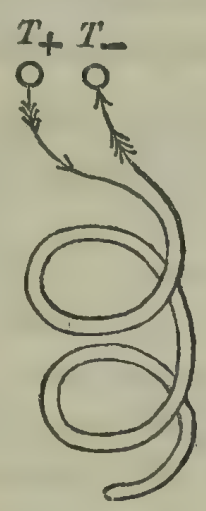


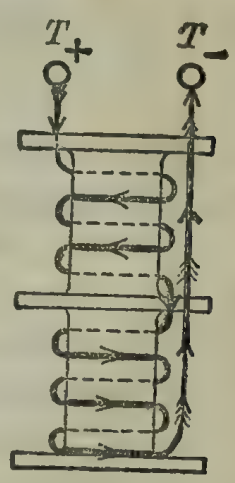
Testing when Winding Wire on Bobbins.—When coiling wire upon any metal bobbin or electro magnet for a dynamo, &c., always keep

on a *continuous* insulation resistance or non-conductivity test, as per above sketch. The inner end of wire is "free" or insulated, the outer end being joined to a sensitive galvanometer, G, capable of detecting the slightest fall in insulation resistance, from 1 megohm or more, when kept in circuit with battery, B, by means of the key, K.

Diameter and Weight of Covered Wires.—When it is required to find the diameter, *d*, of any particular covered wire, or its length per pound, refer to tables; or, take a specimen of the wire and measure its diameter outside the covering by a micrometer screw gauge, and then weigh a known length of it.

Resistance coils, such as are used for standard resistances or in Wheatstone-bridges, &c. (where it is necessary to prevent the effects of self-induction due to the current, and of magneto-electric induction due to magnets or soft iron





moved in the vicinity of the coils), require to be wound thus, so that the current doubles back on itself.

Or, wind the wire for 1st layer, say right-handed, 2nd layer, left-handed, and so on alternately. Each layer of wire must be secured whilst winding on the next layer, so as to prevent its unwinding. This is generally done by tissue fixed with Chatterton's compound. When the whole bobbin is filled then dip it into paraffin wax and finish off neatly.

For rough work, wind as shown by the last sketch—viz., right-handed on the one-half bobbin, and left-handed on the other.

Intensity of a Magnetic Field.—A rectangular coil is pivotted in the magnetic field, with its plane parallel to the lines of force, and in circuit with a balistic galvanometer, or one having a heavy needle. When quickly turned through an angle, θ, not exceeding 90°, the number of lines cut is n I A sin. θ, and the area swept over is n A sin. θ, where n = number of turns in the coil, A their mean area, and I the intensity of the field. If the coil is placed at right angles to the lines of force and turned through an angle, $\theta = 180°$, the number of lines cut is $2n$ I A, and the area swept through is $2n$ A. The corresponding current is compared with that produced by turning the coil as quickly through a known magnetic field; the currents in each case being proportional to the intensities of the fields. The known field may be the earth's, in which case a relatively larger coil may be used if the unknown field is more intense.

With a magnetic needle oscillating, the square of the number of vibrations in a given time is proportional to the intensity of the field. Compare the unknown field with the earth's.

Horizontal Intensity of the Earth's Magnetism:—

A. Gray, M.A., F.R.S.E., on "Absolute Measurements."

The approximate intensity of the horizontal component of the earth's magnetism at several places is given below, but it must be borne in mind that the value of this element may be greatly altered by iron or magnets near the place of observation. See Appendix on Measurement of H.

Cambridge, . . .	·181	Newcastle, ...	·167
London, ...	·181	Dublin, ...	·167
Birmingham, . . .	·176	Carlisle, ...	·166
Nottingham, . . .	·175	Edinburgh, ...	·162
Stafford, ...	·175	Glasgow, ...	·161
Sheffield, ...	·173	Dundee, ...	·161
Manchester, . . .	·172	Aberdeen, ...	·158
Liverpool, ...	·171	Inverness, ...	·156
York, ...	·171		

List of Magnetic Bodies.—

Paramagnetic.

Iron.
Nickel.
Cobalt.
Aluminium.
Manganese.
Chromium.
Cerium.
Titanium.
Platinum.

Wiedemann found *pure* platinum diamagnetic.

Many ores and salts containing the above metals.

Oxygen gas.

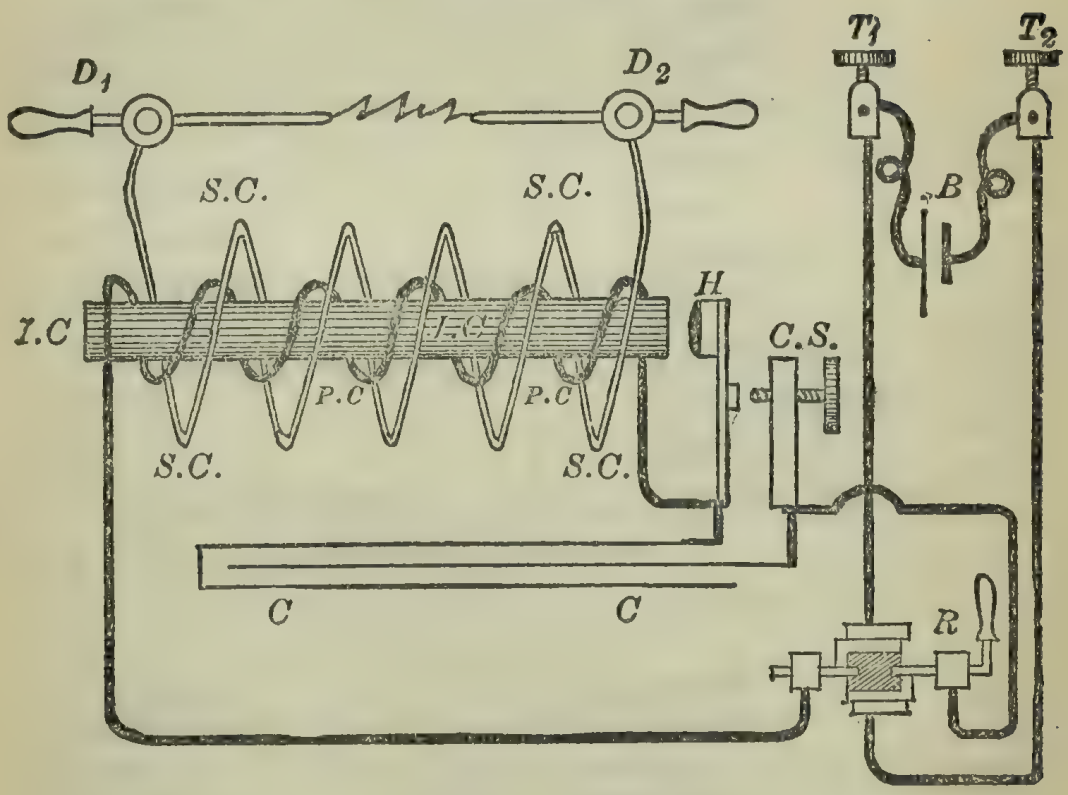
Diamagnetic.

Bismuth.
Phosphorus.
Antimony.
Zinc.
Mercury.
Lead.
Silver.
Copper.
Gold.
Water.
Alcohol.
Tellurium.
Selenium.
Sulphur.
Thallium.
Hydrogen gas.
Air.

If the magnetic power of iron is taken as +1,000,000, that of lodestone ore is +402,270; ferric sulphate, +1,110; ferrous sulphate, +780; water, —7·8; and bismuth, —23·6. —(*Plücker.*)

Connections of Induction Coil.

Ruhmkorff's.



Index to Figure.

T_1 T_2 = Terminals to which wires from
B = Battery are attached.
R = Reverser or commutator for reversing or cutting off current.
CS = Contact screw platinum-pointed (in primary circuit).
H = Hammer (soft iron), the movement of which completes and breaks circuit at CS.
C = Condenser for arresting the momentary direct induced current in
PC = Primary coil of thick wire, through which battery current passes.
SC = Secondary coil of fine wire (well insulated) in which sparking currents are induced.
D_1 D_2 = Spark dischargers fitted to ends of secondary coil.
IC = Iron core, being a bundle of very soft iron wires.

Data of Induction Coils.

Iron Cores.

Spottiswood's Great Coil by Apps.	Diameter of wire—inches	Outside diameter of core—inches.	Length—inches.	Weight—lbs.
...	No. 1, ·032	3·56	44	67
...	No. 2, ·032	3·81	44	92

Primary Coils.

Diameter of wire—inches	B. W. G	Length yds.	Res. ohms.	Weight lbs.	Conductivity °/₀.
·096	13	660	2·3	55	93
·096	13	504	·181 ·211 ·231	84	93

Primary Coils—*continued.*		Secondary Coil.	
Length of Coil—inches.	Method of Winding.	Diameter of wire—inches.	B. W. G.
42 42	1344 turns in 6 single layers. 3 pairs of double strand layers	Central part, ·0095 Outside ,, ·011	32 31

Secondary Coil—*continued.*

Length. Miles.	Res. ohms.	Conductivity °/₀.	Length of Coil—inches.	Outside diameter—inches.
280	110,200	94	37·5	20

Condenser.

126 sheets tinfoil, 18″ × 8¼″, separated by two thicknesses varnished paper, ·011 thick, 19″ × 9″ surface.

Battery.

5 quart Grove cells, plates 6¼″ × 3″, gave 28″ spark with smaller primary.

10 quart Grove cells, plates 6¼″ × 3″, gave 35″ spark with smaller primary.

30 quart Grove cells, plates 6¼″ × 3″, gave 42″ spark with smaller primary.

Rules for Erecting Lightning Conductors.*

By A. Jamieson, C.E., F.R.S.E.

1. The spear or top of the lightning conductor should terminate in 4 or 5 well-gilded or platinised points, and be raised *one* foot above the highest point of the building for every 10 feet of perpendicular height above the ground.

2. The copper rod carrying the spear should be fixed by a screwed coupling, and carefully soldered to a flat bar, rod, tube, or strand rope, of at least 90 °/₀ pure copper, and not less than No. 3 S.W.G., or $\frac{1}{4}$ inch diameter. This gives a cross area of ·05 sq. in., weighs ·6 lb. per yard, and has 1 ohm resistance per mile of length. Since iron corrodes easily when exposed, even if galvanised, it should not be used for lightning conductors unless frequently and very carefully inspected. If used, it should have 8 times the section area or weight of the above copper conductor, *i.e.*, equal to a rope or rod $\frac{3}{4}$-inch diameter.

3. The conductor should be connected to all prominent metallic portions of the building, and *on no account should it be insulated by glass or other means.*

4. All joints in or to the conductor should be thoroughly well made and soldered, and these should be as few as possible in the main conducting cable.

5. The lower end of the conductor should make good and permanent earth, by being terminated in a copper plate at least 6 feet square, embedded in coke, moist earth, or in a

* See Index for page, &c., testing lightning conductors.

well, or soldered to the water pipes, or preferably bolted to the water mains.

6. After the conductor has been erected, it should be carefully tested electrically with battery and galvanometer to see that it offers a minimum of resistance to earth (not more than an ohm, *including everything*), and this should be repeated periodically, say once a year, more especially in the dry season. Mr. Preece states that a conductor will protect a conical space, the radius of whose base equals the vertical height of the conductor above the ground and of the same height as the conductor.

Gyrostatic Action on Dynamos in Ships.

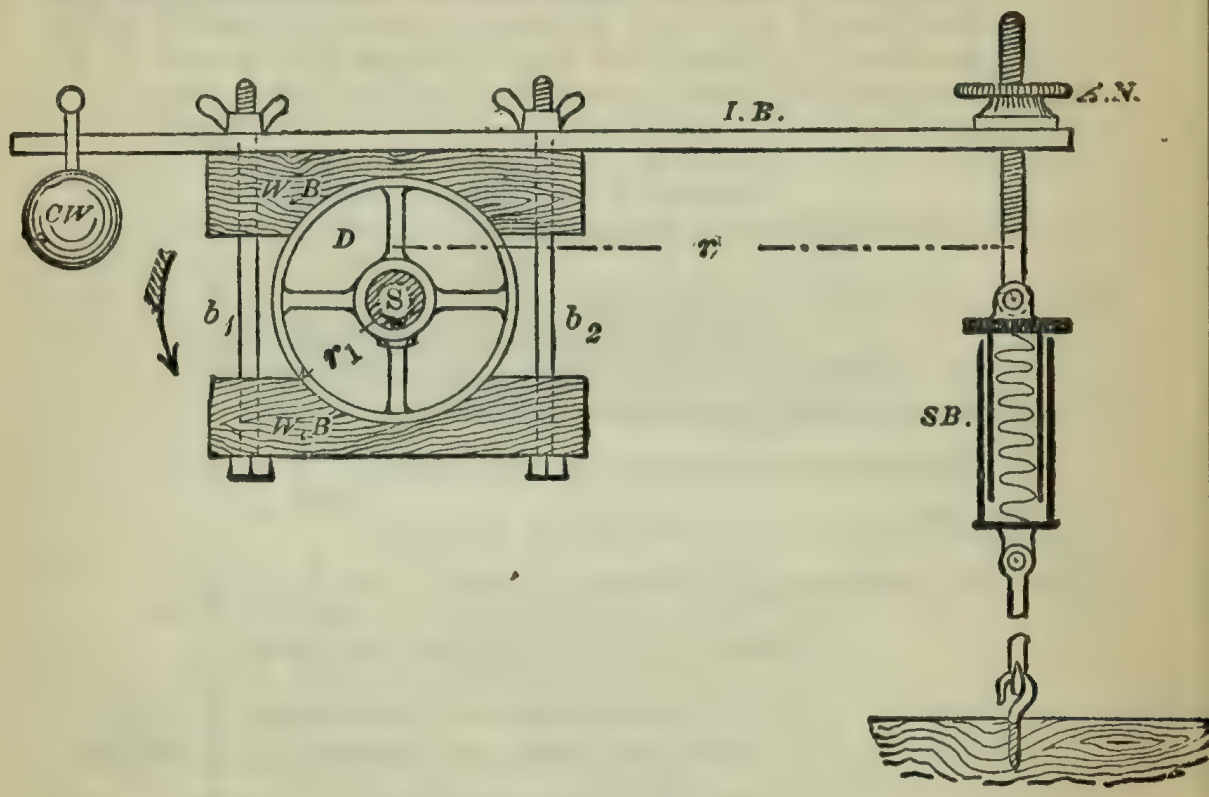
(*Sir William Thomson*).

$$L = \frac{Wk^2\Omega\,\omega}{g} \text{ and } P = \frac{Wk^2\Omega\,\omega}{gl}.$$

where L = moment of couple on axis.
P = pressure on each bearing.
W = weight of Armature.
k = radius of gyration about axis.
$\Omega = \frac{2\pi}{T} A$ = maximum angular velocity of dynamo in radians per second due to rolling of ship.
$A = \frac{\pi d}{180}$ = amplitude in radians per second. (Radian is unit angle in circular measure).
d = degrees of roll from mean position.
T = periodic time in seconds.
$\omega = 2\pi n$ = angular velocity of armature in radians per second.
n = number of revolutions of armature per second.
l = distance between bearings.
g = acceleration due to gravity.

Note.—On applying the above formula to dynamos, where W, k, and ω are great, it will be found advisable to place their plane of rotation athwart ships, in order to avoid as far as possible wear and tear of bearings due to the gyrostatic action.

Prony Brake or Absorption Dynamometer.



Index to Parts.

Where W B	represents	Wooden blocks to fit.
D	"	Drum or pulley keyed to
S	"	Driving shaft.
b_1 b_2	"	Iron bolts with ram's horn nuts to adjust the tightness of W B on D.
I B	"	Stiff iron bar with
S B	"	Salter's balance at one end, and
C W	"	Small counter weight to balance extra length of I B and S B on other side.
A N	"	Adjusting nut for Salter's balance.

Method of taking Test.

1st. Adjust position of C W until it balances the weight of I B, A N, and S B, with the wooden blocks slack on pulley.

2nd. Start machinery and tighten blocks, W B, by ram nuts until desired speed is attained, at same time adjusting S B by nut, A N, until a balance is obtained, keeping I B level.

Note number of revolutions per minute by speed indicator and stress indicated by spring balance.

$$\text{H.P.} = \frac{2\,\pi\,r\,n\,\text{P}}{33000} \text{ horse-power developed on brake.}$$

Where r = horizontal distance from centre of balance to centre of shaft S in feet.
n = number of revolutions per minute.
P = Salter's balance reading in lbs.

$$\text{Since } \frac{2\pi}{33000} = \cdot 0001904 = \text{a constant.}$$

$$\text{H.P.} = \cdot 0001904 \times r \times n \times \text{P}$$

Ex.—Test, taken May, 1883, by A. Jamieson, of fast-speed Westinghouse engine (diameter of cylinder 7-inch, stroke 5-inch, pressure of steam 55 lbs.), with crank shaft coupled direct to an Edison dynamo.

The blocks W B were fixed to a fly-wheel of 2 feet diameter, which was 6 inches broad.

$$r = 2\cdot 5 \text{ feet}; \; n = 624; \; \text{P} = 48 \text{ lbs.}$$

$$\therefore \text{H.P.} = \cdot 0001904 \times r \times n \times \text{P}$$
$$= \cdot 0001904 \times 2\cdot 5 \times 624 \times 48.$$

See index for table of logs.

log.	·0001904	$= \bar{4}\cdot 2797$
,,	2·5	$= 0\cdot 3979$
,,	624·	$= 2\cdot 7952$
,,	48·	$= 1\cdot 6812$
Add		$1\cdot 1540$ number $= 14\cdot 26$ H.P.

NOTE.—It is important to note that neither the diameter of the pulley nor the pressure of the friction blocks on the same (due to the weight of the apparatus, or the tightening of the ram nuts), nor the coefficient of friction enter into the formula for obtaining the horse-power. The only data required being the horizontal length of lever r, the pull P, and the number of revolutions per minute n.

For let p be the pressure, and f the coefficient of friction between the face of the drum D and two brake blocks, W B, then the twisting moment T tending to turn the brake blocks round with the shaft is

$$T = 2\,p\,f \times r_1$$

Where r_1 is the radius of the pulley or drum, D, in feet.

But this twisting moment is balanced by the pull on the spring balance P, multiplied by its leverage r.

$$\therefore\ P\,r = 2\,p\,f\,r_1$$

And since $2\,\pi\,r =$ the circumference of the circle which would be described by the lever I B if allowed to turn with shaft, $\therefore 2\,\pi\,r\,n =$ the space which P would pass through in n revolutions.

$\therefore$ The foot-pounds of work done in n revolutions is

$$2\,\pi\,r\,n\,P = 2\,p\,f \times 2\,\pi\,r_1\,n$$

$$\text{and } \therefore \text{ the H.P.} = \frac{2\,\pi\,r\,n\,P}{33000}$$

It is sometimes advisable to add a dash pot to the lever I B in order to get steady readings of the Salter's balance or weight P.

For a complete treatise on dynamometers see *The Electrician*, Nov. and Dec., 1883; also Goodeve's "Principles of Mechanics," 1883 edition, pp. 188–191.

Melting Point of Metals and Alloys.

Mercury,	-38°	Fah.
Tin,	442°	,,
Bismuth,	497°	,,
Lead,	612°	,,
Zinc,	773°	,,
Antimony,	810°	,,
Brass,	1,869°	,,
Silver,	1,873°	,,
German Silver, about	2,000°	,,
Copper,	1,996°	,,
Gold,	2,016°	,,
Iron, Cast,	2,786°	,,
,, Wrought,	3,286°	,,
Nickel (approximately),	2,800°	,,
Manganese, ,,	3,000°	,,
Platinum,	3,286°	,,

Fusible alloys.—For safety plugs and fire alarms.

(Fusible amalgam.)

Melting at 53° C.—Arcet's metal 9 parts.
Mercury 1 ,,
(Wood's alloy.)

,, 66°-71°—Lead 2 parts.
Tin 4 ,,
Bismuth 7 to 8 ,,
Cadmium 1 to 2 ,,
(Arcet's metal.)

,, 94° C.—Lead 5 parts.
Tin 3 ,,
Bismuth 8 ,,

,, 210° F.—Tin 3, lead 5, bismuth about 8 parts.

,, 246° F.—Tin 4, bismuth 5, lead 1 part.

,, 286° F.—Tin 1, bismuth 1 ,,

,, 334° F.—{ Tin 2, bismuth 1 ,,
{ Tin 3, lead 2 ,,

TABLE GIVING ALLOYS USED IN ELECTRICAL INSTRUMENT WORK.

By Messrs. Bowen & Co., Brass Founders, London.

	Tin.	Copper.	Zinc.	Nickel.	Scrap Brass.
"Free" Brass, ...	...	2	1	...	...
Common Brass, ...	...	1	1	...	1
"Deep Red Gun" Metal, . . .	1	9	...	...	...
"Best" Gun Metal, ...	1	8	...	...	...
German Silver, Best, ...	...	2	1	1	...
,, ,, 2nd Quality, . .	...	2	1	·5	...
Babbett's Metal, ...	10	1	...	...	...

Red and Best Gun Metals ought to have 1½ lbs. per cwt. of Zinc added, and the alloy should be melted twice to ensure *sound* castings. In making German Silver, the nickel and copper are placed in layers in the crucible and the zinc added afterwards.

Alloys used in Electrical Work.

Alloys.	Tin.	Copper.	Zinc.	Antimony.	Lead.	Bismuth.
Brass, engine bearings, . .	13	112	¼	..	..	..
Tough brass, engine work, .	15	100	15	..	..	..
„ for heavy bearings,	25	160	5	..	..	..
Yellow brass, for turning, .	..	2	1	..	..	..
Flanges to stand brazing, . .	..	32	1	..	1	..
Bell-metal, ...	5	16	..	..	..	..
Babbett's metal, ...	10	1	..	1	..	..
Brass, for locomotive bearings	7	64	1	..	..	..
„ for straps and glands,	16	130	1	..	..	..
Muntz's sheathing, ...	..	6	4	..	..	..
Metal to expand in cooling, .	..	..	..	2	9	1
Pewter, ...	100	..	..	17	..	..
Spelter, ...	..	1	1	..	..	..
Statuary bronze, ...	2	90	5	..	2	..
Type-metal, ... from	..	..	..	1	3	..
„ . . . . . to	..	..	..	1	7	..
Solders.						
For lead, ...	1	..	..	..	1½	..
„ tin, ...	1	..	..	..	2	..
„ pewter, ...	2	..	..	..	1	..
„ brazing (hardest), . . .	..	3	1	..	..	..
„ „ (hard), ...	..	1	1	..	..	..
„ „ (soft), ...	1	4	3	..	..	..
„ „ „ . . or	2	..	..	1	..	..

SOLDERING. — For electric apparatus resin should be used as flux. If chloride of zinc is used, it harbours damp, besides corroding the metals. Iron line wires are soldered together by chloride of zinc solution (zinc dissolved in spirit of salt), with a little HCl added to clean the surfaces. Rain cleans the joint. When copper wire is soldered to iron, zinc, &c., resin should be used, or if chloride of zinc, the joint should be washed afterwards to remove the acid. Unannealed wires should be soldered at as low a temperature as possible. Good solder is known by its emitting the "cry of the tin" on bending a stick.

Solders. —

	Parts.
Soft spelter solder (for common brass-work),	1 copper, 1 zinc. 1½ ,, 6 ,, or 10 brass.
Hard spelter solder (for iron), ...	2 ,, 1 ,,
For fine brass-work, .	8 ,, 8 ,, 1 silver.
For steel, ...	3 ,, 1 ,, 19 ,,
Hard silver solder, . .	1 ,, — ,, 4 ,,
Soft ,, ,, . .	2 silver, 1 brass wire.
Gold solder, ...	24 gold, 2 silver, 1 cop.

Silver solders are used for joining the individual wires in cables, and fine work in apparatus. They are very fusible and non-corrosive.

Coarse tin solder, . .	tin, 1; lead, 2 to 3.
Common ,, ,, . .	,, 1; ,, 1.
Fine ,, ,, . .	,, 2; ,, 1.

These are used for line wires, the last being best.

Pewterer's soft solder (for lead), ...	bismuth 2 parts, lead 4, tin 3.
Pewterer's common solder, ...	bismuth 1 ,, ,, 1, tin 2.
Pewterer's com. solder, fusing at 320° Fah., .	bismuth 8 ,, ,, 4, tin 4.
Pewterer's com. solder, fusing at 202° Fah., .	bismuth 8 ,, ,, 3, tin 5.

Mercury reduces the fusing point still further. These solders are useful for soldering tinfoil, lead tubes, and covered wires. The tenacity of fine tin solder is about 7500 lbs. per square inch.

Fluxes for Soldering or Welding.

Iron or steel, . .	Borax or sal-ammoniac.
Tinned iron, . .	Resin or chloride of zinc.
Copper and brass,	Sal-ammoniac or chloride of zinc.
Zinc, ...	Chloride of zinc.
Lead, ...	Tallow or resin.
Lead and tin pipes,	Resin and sweet oil.

Solder for Low Temperatures.—Take finely divided copper, precipitated from sulphate of copper solution by zinc, and mix it with concentrated sulphate of mercury solution in a porcelain mortar. Take 30 to 36 parts of this treated copper, according to hardness, and 70 of mercury, stirring them together. When the amalgam is sufficiently formed, wash away all trace of acid

with hot water. In using, heat till it becomes waxy, and smear the surfaces to be united. When cold they adhere.

Brazing.

The edges filed or scraped clean and bright, covered with spelter and powdered borax and exposed in a clear fire to a heat sufficient to melt the solder.

Case-hardening.

Place horn, hoof, bone-dust, or shreds of leather, together with the article to be case-hardened, in an iron box subject to a blood-red heat, then immerse the article in cold water.

Some engineers cut up the shreds, &c., fine, and mix them with white wine vinegar and salt.

Case-hardening with Yellow Prussiate of Potash.

Heat the articles after polishing to a bright red, rub the surface over with prussiate of potash; allow it to cool to dull red, and immerse it in water.

Case-hardening Mixtures.

3 prussiate of potash to 1 of sal-ammoniac mixed, or 2 sal-ammoniac, 2 of bone-dust, and 1 of prussiate of potash.

Lacquer for Brass.—8 oz. shellac dissolved in 1 gallon spirits of wine; or 8 oz. shellac, 2 oz. gum sandarac, 2 oz. annato, ¼ oz. dragon's blood, dissolved in 1 gallon spirits of wine.

Lacquer for Iron.—3 lbs. asphalt, ½ lb. shellac, dissolved in 1 gallon of turpentine; or 12 of amber, 12 of turpentine, 2 of asphalt, and 6 oz. of drying oil.

Bronzing Brass by Simple Immersion.

By Messrs. Bowen & Co., Brass Founders, &c., London.

	Water.	Nitrate of iron.	Perchloride of iron.	Permuriate of iron.	Nitrate of copper.	Tersulphide of arsenic.	Muriate of arsenic.	Potash solution of sulphur.	Pearl-ash solution.	Cyanide of potassium.	Ferro-cyanide of potassium.	Sulpho-cyanide of potassium.	Hypo-sulphide of soda.	Nitric acid.	Oxalic acid.	Colour.
No.	pt	dr	dr	pt	oz	gr	oz	dr	dr	oz	pt	dr	dr	dr	oz	
1	1	5	..	..	..	..	..	..	..	..	..	..	..	..	..	Brown & every shade to black.
2	1	..	5	..	..	..	..	..	..	..	..	..	..	..	..	Brown & every shade to black.
3	1	16	..	..	..	..	..	..	...	..	..	..	16	..	..	Brown & every shade to red.
4	1	..	..	..	..	..	..	..	..	..	..	..	16	1	..	Brown & every shade to red.
5	1	..	..	..	1	..	..	..	..	..	..	..	..	..	1	Brownish red.
6	..	..	..	..	..	..	..	..	..	..	1	..	..	3	..	Brownish red.
7	1	..	..	..	..	..	..	..	.	1	..	..	..	4	..	Dark brown.
8	1	..	..	..	..	30	..	..	6	..	..	.	..	..	..	Yellow to red.
9	1	..	..	..	..	..	..	1	..	..	..	..	..	..	..	Orange.
10	2	..	..	1	..	..	..	..	..	..	..	..	..	..	..	Olive-green.
11	1	..	5	..	..	..	..	..	..	..	..	2	..	..	..	Slate.
12	1	..	..	..	..	..	..	..	..	..	..	..	20	..	..	Blue.
13	1	..	..	..	..	..	1	..	..	..	..	..	..	..	..	Steel-gray.
14	1	..	..	2	..	..	10	..	..	..	..	..	..	..	..	Black.

N.B.—In preparation of No. 5, liquid must be brought to boil and cooled. In using No. 13, the heat of the liquid must not be under 180°. No. 6 is slow in action.

The action of the others is for the most immediate.

Contraction of Castings.

By Messrs. Bowen & Co., Brass Founders, London

	inch.	inches of length.
In thin Brass castings,	$\frac{1}{8}$	in 9
,, thick ,, ,,	$\frac{1}{8}$	,, 10
,, Zinc castings,	$\frac{5}{16}$	,, 12
,, Lead, according to purity,	$\frac{3}{16}$ to $\frac{5}{16}$	,, 12
,, Copper, ,, ,,	$\frac{3}{16}$,, $\frac{7}{32}$	,, 12
,, Tin, ,, ,,	$\frac{1}{32}$,, $\frac{1}{16}$	,, 12
,, Silver, ,, ,,	$\frac{1}{8}$	,, 12
,, Cast Iron, ,, ,, small castings	$\frac{1}{10}$	,, 12
,, Cast Steel, ,, ,, pipes,	$\frac{1}{8}$	,, 12

The above values fluctuate with the form of pattern, amount of ramming, and temperature of metal when poured. Green sand castings contract less than loam or dry sand castings.

Table giving Proportionate Weight of Casting to Weight of Wood Pattern.

By Messrs. Bowen & Co., Brass Founders, London.

A Pattern weighing One Pound made of (*Less weight of core prints*)	Cast Iron.	Brass.	Copper.	Bronze.	Bell Metal.	Zinc.
	lbs	lbs	lbs	lbs	lbs	lbs
Pine or Fir will weigh in .	14	15·8	16·7	16·3	17·1	13·5
Oak ,, ,, .	9	10·1	10·4	10·3	10 9	8·6
Beech ,, ,, .	9·7	10·9	11·4	11·3	11·9	9·1
Linden ,, ,, .	13·4	15·1	16·7	15 5	16·3	12·9
Pear ,, ,, .	10·2	11·5	11·9	11·8	12·4	9·8
Birch ,, ,, .	10·6	11·9	12·3	12·2	12·9	10·2
Alder ,, ,, .	12·8	14·3	14·9	14·7	15·5	12·2
Mahogany ,, ,, .	11·7	13·2	13·7	13·5	14·2	11·2
Brass ,, ,, .	0·84	0·95	0·99	0·98	1·0	0·81

TABLE—

SHOWING HOURS OF LIGHTING THROUGHOUT A YEAR OF 8,760 HOURS.

DAILY LIGHTING.	January.	February.	March.	April.	May.	June.	July.	August.	Sept.	October.	Nov.	Dec.	Total per Annum.
From sundown to 8 p.m., . .	125	89	67	36	6	...	...	21	54	87	117	140	742
,, ,, 9 ,, . .	156	117	98	66	37	20	25	52	84	118	147	171	1,091
,, ,, 10 ,, . .	187	145	129	96	68	50	56	83	114	149	177	202	1,456
,, ,, 11 ,, . .	218	173	160	126	99	80	87	114	144	180	207	233	1,821
,, ,, midnight, . .	249	201	191	156	130	110	118	145	174	211	237	264	2,186
,, ,, 2 a.m., . .	311	257	253	216	192	170	180	207	234	273	297	326	2,916
,, ,, 4 ,, . .	373	313	315	276	254	230	242	269	294	335	357	388	3,646
From 4 a.m. to sunrise, . .	125	92	69	32	3	...	...	24	51	75	103	154	728
,, 5 ,, ,, . .	94	64	38	2	...	...	...	...	21	44	73	123	459
,, 6 ,, ,, . .	63	36	7	...	...	...	...	...	...	13	43	63	254

Recipes.

Electro-chemical Printing Solution (*Bain's*).—Saturated solution of potassium ferro-cyanide 1 part, water 2 parts; or, saturated solution of ammonium nitrate 1 part, water 2 parts.

Silver for Mirrors.—Tin 4 parts, mercury 1.

Amalgam for Electric Rubbers.—The rubbers of glass electric machines are coated with amalgam, consisting of equal weights of tin and zinc melted together, with twice their joint weight of mercury added during fusion.—(*Kienmayer.*) Another amalgam is tin 1, zinc 2, mercury 4. For ebonite discs the amalgam should be softer than for glass. Grease is mixed with the powdered amalgam to give it softness and make it stick. In France bisulphuret of tin is used.

Purifying Mercury.—Place the mercury in a deep vessel with dilute acid over it, and introduce a piece of copper into it, weighting the copper to make good contact. The local action dissolves all impurities. If continued too long the mercury becomes sulphate.

To Platinise Silver.—For use in Smee cells. The silver plate to be coated is plunged in a bath of bichloride of platinum and acidulated water. A current is sent through the bath from a platinum anode, the silver serving as cathode. A rough coating of platinum takes place on the silver.

To Platinise Carbon (*Walker.*)—The carbon plate is purified by immersion for several days in sulphuric acid diluted with three or four times its volume of water, then put into a bath of sulphuric acid diluted with ten times its volume of water, with crystals of chloride of platinum added until it becomes straw coloured.

The carbon is connected to the – pole of the battery, and a platinum or carbon plate connected to the + pole serves for anode. After 20 minutes the carbon is platinised, as may be proved by using it to decompose water. The hydrogen should freely rise from its surface.

To platinise iron.—Steep the iron plate in an acid solution of platinum in *aqua regia*.

Insulating varnishes. — *Red varnish* for wood, &c., sealing wax dissolved in alcohol, and painted on with a brush in successive thin layers, say four or five.

For Galvanometer Coils.—Gum copal dissolved in ether, painted over each layer of wire and dried on a stove.

Shellac Varnish (Harris).—Put 1 ounce shellac into a wide-mouthed 8 ounce phial containing 5 ounces of rectified naphtha or wood spirit. Cork and stand in a warm place until the gum is dissolved. Shake frequently and filter, adding more naphtha to assist the filtering, and changing the filter from time to time.

For Silk.—Mix 6 ounces of boiled linseed oil, and 2 ounces of rectified spirits of turpentine.

For large Coils.—Cotton-covered wires are now steeped in melted paraffin to increase their insulation. Large electro-magnet coils have a double covering of cotton, and the outer layer is coated with a thick varnish of shellac dissolved in alcohol.

Insulating paper.—Absorbent tissue paper is rendered insulating by steeping it in melted paraffin, and is used for the dielectric of large telegraph condensers, and Muirhead's artificial cable. An insulating varnish for paper is made by mixing one part of Canada balsam and two

parts of essence of turpentine. Digest in a bottle with a gentle heat, and filter before cooling.

Saturating Tapes (*Madsen*).—Stockholm pitch 8 parts, wax 2 parts, tallow 1 part.

Battery pomade, for checking the creeping of solutions in cells; paraffin wax 2 parts, vaseline 1 part melted together.—(*Thompson.*)

Insulating Wood.—Wood for battery jars, &c., is also rendered insulating by steeping it in, or brushing it with, melted paraffin.

For Galvanoplasty.—An oaken trough, close made, and will last from twelve to fifteen years if coated with

Burgundy pitch, ...	1 500	grammes.
Old G. P. in shreds, . . .	250	"
Pounded pumice, ...	750	"

Melt the G. P., mix with the pumice, and add the pitch. Apply liquid to the trough in several coats. A hot iron passed over the surface smooths it, and assists adhesion. The box resists sulphate of copper baths, but not cyanides.—(*E. Berthould.*)

In India, **wooden bobbins** for telegraphic apparatus are dried for five hours at a temperature not less than 230 F., then at once plunged into a melted mixture of ten parts yellow resin, one part white wax at 350° F. When the escape of air-bubbles ceases, the bobbins are taken out and allowed to drip. They are then wound with wire, and again treated in this way three times over. The temperature of the mixture may, however, be less at each immersion. No paper is permitted between the layers, as it diminishes the magnetic effect, and prevents the mixture penetrating.—(*Schwendler.*)

Ebonite. — Sulphur two to three parts is

mixed with caoutchouc, five parts, and cured for several hours at 75° C., under a pressure of four to five atmospheres. Ebonite is apt to become porous, and conductive in moist air or in sunlight. It keeps best when dry and in the dark. Heat softens and deforms it. To prevent loss of insulation by oxidation of the sulphur, the surface should be washed from time to time with boiling water, then rinsed with distilled water, and dried. The surface should be shellaced or paraffined, especially in moist climates.

Hard Good Quality:—

Best Para rubber	2	parts by weight.
Sulphur	1	,,

American Ebonite:—

Rubber	12	,,
Sulphur	8	,,
Whiting	1	,,
Wash	1	,,

Curing moulds for above—

Lead	2	,,
Antimony	1	,,

Soft vulcanised India-rubber:—

Para rubber	7·5	,,
Sulphur	·75	,,
Lime	·01	,,
Whiting	7·5	,,
French chalk	1·25	,,
Litharge	1·5	,,

Glass Insulating Stems are cleaned by washing with hot water and clean soap, then drying with a fine cloth or silk ribbon. Damp is prevented from settling on them by surrounding them with strong sulphuric acid, in a cup containing pumice stone, to dry the air. See that the acid does not become saturated with moisture, and corrode the metal work near.

Insulating cement.—For *experimental work* a useful cement is made by melting together resin, bees'-wax and guttapercha in varying proportions. Sealing wax is also useful, especially the best qualities.

Cement for Insulators.—Sulphur, lead, or plaster of Paris mixed with a little glue to prevent too rapid settling.

Muirhead's Cement.—Three lbs. Portland cement, three lbs. rough sand, four lbs. smithy ashes, and four lbs. resin.

Black Cement.—One lb. smithy ashes, one lb. rough sand, two lbs. resin.

Siemens' Cement.—Twelve lbs. black iron rust, or iron filings, 100 lbs. sulphur.

Glue Cement; resisting damp,—one glue, one black rosin, four red ochre mixed with least quantity of water; or four glue, one boiled oil by weight, three oxide of iron.

Cement for Leather.—Sixteen guttapercha, four india-rubber, two pitch, one shellac, all cut small, with two of linseed oil, melted together and well mixed.

Acid-proof Cement.—A cement, which may be useful to electricians, is made by dissolving caoutchouc by carefully heating it in twice its weight of linseed oil, and then adding twice its

weight of pipe-clay. The product forms a very plastic acid-proof mass, which, when heated, becomes softer, but does not melt. It can be kept for a long time in a damp place without hardening. When it becomes hard it can be softened again by oil of turpentine.

Heat and acid-proof Cement.—

Sulphur, ...	100 parts.
Tallow, ...	2 ,,
Resin, ...	2 ,,

Melt these together to a ruddy syrup, add sifted ground-glass to form a paste, and heat when used.

Cement for Glass and Metal.—Best and purest gum arabic is put into a small quantity of water, and left till next day, when it is of the consistence of treacle. Calomel (mercurous chloride or subchloride of mercury, 9d. per oz.) is then added to make a sticky mass, and well mixed on a glass plate with a spatula. No more is to be made than that required for immediate use. The cement hardens in a few hours, but it is better to leave it for a day or two.

Cement for Incandescent Lamp Filaments.—Take 100 grains carburet of iron (Dixon's stone polish), grind dry to a fine powder, add 10 grains lump sugar, mix well in a mortar; then add 40 grains gold bronze, mix again; then add sufficient water to make a thick paste, and apply it to the junction between the carbon and the platinum wire; allow it to stand for 20 minutes or so, then burn the joint to a cherry-red heat by a fine gas flame.

Compounds (*Chatterton's*) for joining the layers of G.-P. in cable core.—Stockholm tar 1, resin 1, guttapercha 3 parts.

Clark's for coating the sheathing of cables.—Mineral pitch 65, sand 30, tar 5 parts.

SPECIFIC HEAT OF SUBSTANCES,

BY REGNAULT AND OTHERS.

From D. K. Clark's "Rules, Tables, and Data," at between 32° and 212° Fah., unless stated.

Water at 39°·1 F.,	1·000
,, ,, 212° F.,	1·013
Ice at 32°,	·504
Steam at 212°,	·480
Mercury,	·033
Iron, cast,	·130
,, wrought,	·113
Steel, soft,	·116
Copper,	·095
Lead,	·031
Zinc,	·093
Tin,	·057
Silver,	·057
Platinum, sheet,	·0324
,, spongy at 952° F.,	·035
Coal,	·240
Coke,	·200
Olive oil,	·310
Air,	·238
Carbonic oxide,	·248
Carbonic acid,	·217
Hydrogen,	3·404
Oxygen,	·218
Nitrogen,	·244

For more complete tables see Rankine's *Rules and Tables*, 7th edition, or D. K. Clark's *Rules, Tables, and Data.*

Whitworth's Standard for Screws with Angular Threads

No. of Threads per inch.	Old Sizes, inches.	New Standard, decimals of an inch.	No. of Threads per inch.	Old Sizes, inches.	New Standard, decimals of an inch.	No. of Threads per inch	Old Sizes, inches.	New Standard, decimals of an inch.
48		·100	12		·600	4	$2\frac{3}{8}$	2·375
40	$\frac{1}{8}$	·125	11	$\frac{5}{8}$	·625	4	$2\frac{1}{2}$	2·500
32		·150	11		·650	4	$2\frac{5}{8}$	2·625
24		·175	11		·675	$3\frac{1}{2}$	$2\frac{3}{4}$	2·750
24		·200	11		·700	$3\frac{1}{2}$	$2\frac{7}{8}$	2·875
24		·225	10	$\frac{3}{4}$	·750	$3\frac{1}{2}$	3	3·000
20	$\frac{1}{4}$	·250	10		·800	$3\frac{1}{4}$	$3\frac{1}{4}$	3·25
20		·275	9	$\frac{7}{8}$	·875	$3\frac{1}{4}$	$3\frac{1}{2}$	3·50
18		·300	9		·900	3	$3\frac{3}{4}$	3·75
18		·325	8	1	1·000	3	4	4·00
18		·350	7	$1\frac{1}{8}$	1·125	$2\frac{7}{8}$	$4\frac{1}{4}$	4·25
16	$\frac{3}{8}$	·375	7	$1\frac{1}{4}$	1·250	$2\frac{7}{8}$	$4\frac{1}{2}$	4·50
16		·400	6	$1\frac{3}{8}$	1·375	$2\frac{3}{4}$	$4\frac{3}{4}$	4·75
14		·425	6	$1\frac{1}{2}$	1·500	$2\frac{3}{4}$	5	5·00
14		·450	5	$1\frac{5}{8}$	1·625	$2\frac{5}{8}$	$5\frac{1}{4}$	5·25
14		·475	5	$1\frac{3}{4}$	1·750	$2\frac{5}{8}$	$5\frac{1}{2}$	5·50
12	$\frac{1}{2}$	·500	$4\frac{1}{2}$	$1\frac{7}{8}$	1·875	$2\frac{1}{2}$	$5\frac{3}{4}$	5·75
12		·525	$4\frac{1}{2}$	2	2·000	$2\frac{1}{2}$	6	6·00
12		·550	$4\frac{1}{2}$	$2\frac{1}{8}$	2·125			
12		·575	4	$2\frac{1}{4}$	2·250			

Whitworth's Gas Threads.

Diameter in inches	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2
No. of Threads per inch	28	19	19	14	14	11	11	11	11	11

SCREWS.—Angle of thread = 55°.

$\frac{1}{6}$ of depth is rounded off at top and bottom.

Number of threads to the inch in square threads = $\frac{1}{2}$ number of those in angular threads.

Depth of threads = ·64 pitch for angular, = ·475 pitch for square threads.

WHITWORTH'S STANDARD NUTS AND BOLT-HEADS.

Diam. of Bolt, inches.	Width across Flats.	Thickness of Nuts.	Thickness of Bolt-heads.	Diam. of Bolt at Bottom of Thread.	Diam. of Bolt, inches.	Width across Flats.	Thickness of Nuts.	Thickness of Bolt-heads.	Diam. of Bolt at Bottom of Thread.
$\frac{1}{8}$	·338	$\frac{1}{8}$	·1093	·0929	$1\frac{1}{8}$	1·8605	$1\frac{1}{8}$	·9843	·942
$\frac{3}{16}$	·448	$\frac{3}{16}$	·1640	·1341	$1\frac{1}{4}$	2·0483	$1\frac{1}{4}$	1·0937	1·067
$\frac{1}{4}$	·525	$\frac{1}{4}$	·2187	·1859	$1\frac{3}{8}$	2·2146	$1\frac{3}{8}$	1·2031	1·1615
$\frac{5}{16}$	·6014	$\frac{5}{16}$	·2734	·2413	$1\frac{1}{2}$	2·4134	$1\frac{1}{2}$	·3125	1·2865
$\frac{3}{8}$	·7094	$\frac{3}{8}$	·3281	·2949	$1\frac{5}{8}$	2·5763	$1\frac{5}{8}$	1·4218	1·3688
$\frac{7}{16}$	·8204	$\frac{7}{16}$	·3828	·346	$1\frac{3}{4}$	2·7578	$1\frac{3}{4}$	1·5312	1·4938
$\frac{1}{2}$	·9191	$\frac{1}{2}$	·4375	·3932	$1\frac{7}{8}$	3·0183	$1\frac{7}{8}$	1·6406	1·5904
$\frac{9}{16}$	1·011	$\frac{9}{16}$	·4921	·4557	2	3·1491	2	1·75	1·7154
$\frac{5}{8}$	1·101	$\frac{5}{8}$	·5468	·5085	$2\frac{1}{8}$	3·337	$2\frac{1}{8}$	1·8593	1·8404
$\frac{11}{16}$	1·201	$\frac{11}{16}$	·6015	·571	$2\frac{1}{4}$	3·546	$2\frac{1}{4}$	1·9687	1·9298
$\frac{3}{4}$	1·3012	$\frac{3}{4}$	·6562	·6219	$2\frac{3}{8}$	3·75	$2\frac{3}{8}$	2·0781	2·0548
$\frac{13}{16}$	1·[illegible]9	$\frac{13}{16}$	·7109	·6844	$2\frac{1}{2}$	3·894	$2\frac{1}{2}$	2·1875	2·1798
$\frac{7}{8}$	1·4788	$\frac{7}{8}$	·7656	·7327	$2\frac{5}{8}$	4·049	$2\frac{5}{8}$	2·2968	2·3048
$\frac{15}{16}$	1·5745	$\frac{15}{16}$	·8203	·7952	$2\frac{3}{4}$	4·181	$2\frac{3}{4}$	2·4062	2·384
1	1·6701	1	·875	·8399	3	4·531	3	2·625	2·634

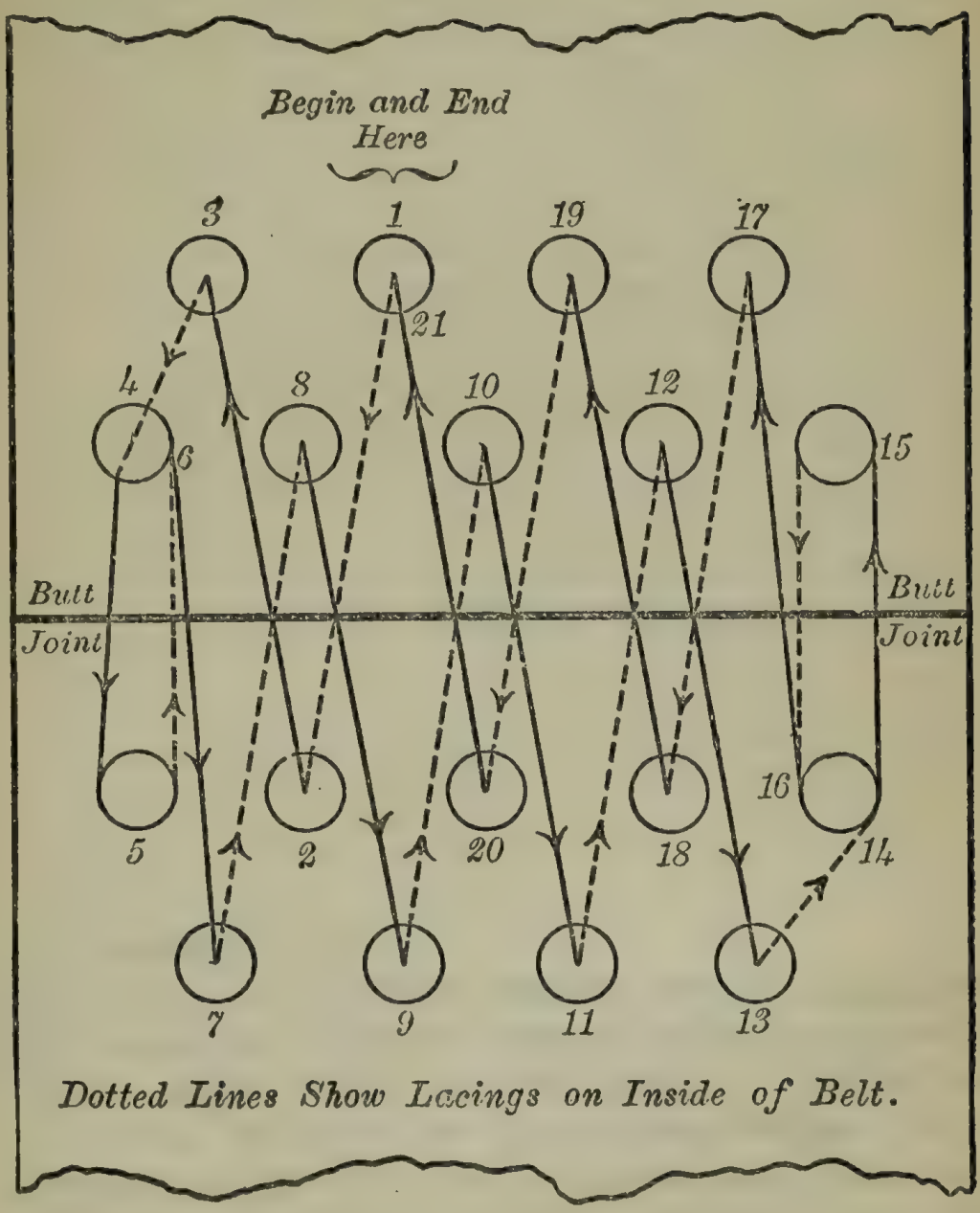
B.A. Standard Small Screw Gauge.

(Adopted by H.M. Postal and Telegraphs Departments.)

Number.	Nominal Dimensions in Thousandths of an Inch.			Absolute Dimensions in Millimetres.	
	Diameter.	Pitch.	Threads per Inch.	Diameter.	Pitch.
I.	II.	III.	IV.	V.	VI.
25	10	2·8	353	0·25	0·072
24	11	3·1	317	0·29	0·080
23	13	3·5	285	0·33	0·089
22	15	3·9	259	0·37	0·098
21	17	4·3	231	0·42	0·11
20	19	4·7	212	0·48	0·12
19	21	5·5	181	0·54	0·14
18	24	5·9	169	0·62	0·15
17	27	6·7	149	0·70	0·17
16	31	7·5	134	0·79	0·19
15	35	8·3	121	0·90	0·21
14	39	9·1	110	1·0	0·23
13	44	9·8	101	1·2	0·25
12	51	11·0	90·7	1·3	0·28
11	59	12·2	81·9	1·5	0·31
10	67	13·8	72·6	1·7	0·35
9	75	15·4	65·1	1·9	0·39
8	86	16·9	59·1	2·2	0·43
7	98	18·9	52·9	2·5	0·48
6	110	20·9	47·9	2·8	0·53
5	126	23·2	43·0	3·2	0·59
4	142	26·0	38·5	3·6	0·66
3	161	28·7	34·8	4·1	0·73
2	185	31·9	31·4	4·7	0·81
1	209	35·4	28·2	5·3	0·90
0	236	39·4	25·4	6·0	1·00

Lacing Belts.—Plan of dynamo belt, showing method of lacing with butt joint and no overlap, so as to run straight and quiet.

The following sketch shows a 6-inch belt with



9 holes on each side. It is capable of transmitting 18 B.H.P. at 3,000 feet per minute; or at the

rate of 1-inch breadth per B.H.P. at 1,000 feet per minute, which is a safe practical rule for dynamos, with an 8-inch pulley and upwards. The lacer used is the Helvation leather lacer $\frac{1}{2}$-inch wide, and in one length. Begin at hole marked 1, and continue through holes in order, 2, 3, 4, &c., as shown, ending with hole 1, also marked 2¦.

Magnetic Measurements.

By Professor J. A. Ewing.

Magnetic Poles, Axis, and Moment.—The magnetism of a bar magnet can be approximately represented as consisting of two *poles*, equal in strength and opposite in sign, situated at the extremities of the magnetic *axis*. In an indefinitely thin bar, uniformly magnetised, the poles would be the terminal points of the bar. Actual bars are never uniformly magnetised, and the distance between their poles is always less than the total length of the bar. *Unit pole* is that which repels with a force of one dyne another equal pole placed at a distance of one centimetre from it. If the pole strength is m, and the distance between the poles l, the *moment* of the magnet, $M, = m\,l$.

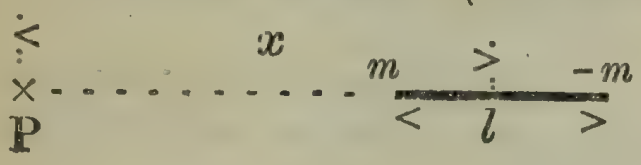
Intensity of Magnetisation.—The external magnetic effect of a magnet is a result of a certain condition of the metal, which extends continuously throughout the bar. A portion cut from any part of the bar will exhibit magnetic qualities, and if the magnetisation of the bar were uniform, every small portion would have a moment proportional to its volume. The moment per unit of volume is called the *intensity of magnetisation*, and is denoted by I. In an actual straight bar magnet the moment divided by the whole volume is the average intensity of magnetisation. In a uniformly magnetised bar, whose cross-section is uniform, the pole strength is $\mathsf{I}s$, where s is the cross-section in square centimetres.

Magnetic Field.—A magnet produces magnetic *force*, denoted by H, in the *field* or space

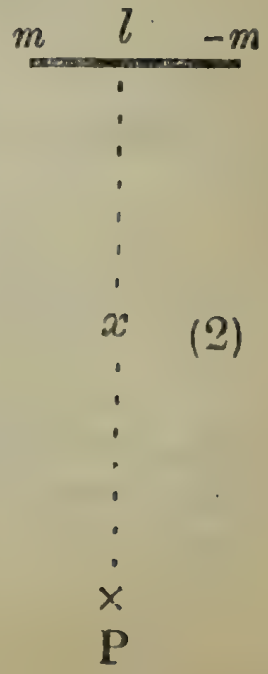
surrounding it. H is measured at any point of the field by the mechanical force which a unit magnetic pole would experience if placed at that point. The magnetic force, H, is also called the strength or intensity of the field. Unit field is that in which a unit magnetic pole would experience a force of one dyne. A uniform field is one in which the force is uniform at all points.

The magnetic force produced at any point by a pole m at a distance d from the point is equal to $\frac{m}{d^2}$, and acts along the line joining the point with the pole. If the field is produced by a magnet equivalent to two poles, m and $-m$, at a distance, l, from each other, the magnetic force at any point, P (distant d_1 from m and d_2 from $-m$), is the resultant of a force $\frac{m}{d_1^2}$ acting along d_1, and $\frac{-m}{d_2^2}$ acting along d_2.

Particular cases.—(See next page.)



(1)



(2)

(1) At a point, P (p. 430), on the axis of the magnet produced, at a distance x from the middle of the bar, the force H acts along the axis, and is equal to

$$\frac{2\,m\,l\,x}{\left(x^2-\frac{l^2}{4}\right)^2};$$

and in the case of an actual bar magnet of moment M and length l,

$$\mathrm{H}=\frac{2\,\mathrm{M}\,x}{\left(x^2-\frac{l^2}{4}\right)^2}\text{ nearly.}$$

(2) At a point, P (p. 430), opposite the centre of the bar, and at a distance x from it, $\mathfrak{H}$ is parallel to the axis of the magnet, and equal to

$$\frac{\mathrm{M}}{\left(x^2+\frac{l^2}{4}\right)^{\frac{3}{2}}}\text{ nearly.}$$

Measurement of Moment.—This is done by comparing the field produced by the magnet at a point in its neighbourhood with the earth's magnetic field there. To find the moment, M, of a magnet, place it in one or other of the two positions sketched (p. 430), pointing towards the magnetic east and west, and with a magnetometer at P. Observe the angle, θ (expressed in circular measure), by which the magnetometer magnet is deflected from the position in which it hangs when the other magnet is not there; or, in other words, when the magnetometer is directed

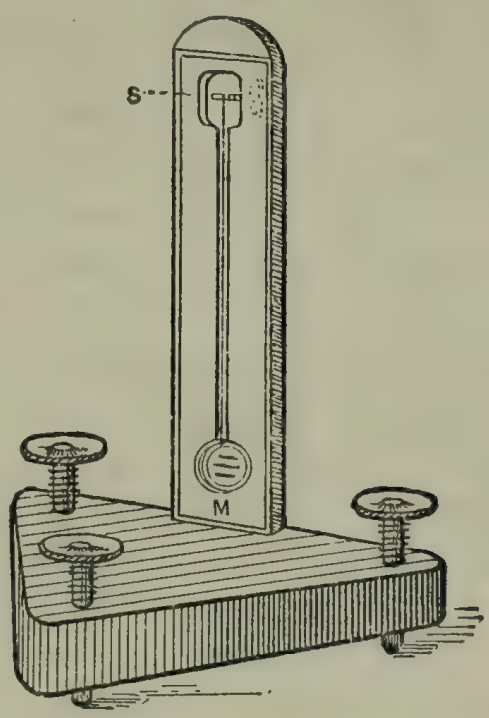
only by the horizontal component, H, of the earth's magnetic force. Then,

$$\text{Field due to magnet} = \mathrm{H} \tan \theta$$

$$\mathrm{M} = \frac{\mathrm{H} \tan \theta}{2x}\left(x^2 - \frac{l^2}{4}\right)^2 \text{ in the first position;}$$

$$\mathrm{M} = \mathrm{H} \tan \theta \left(x^2 + \frac{l^2}{4}\right)^{\frac{3}{2}} \text{ in the second position.}$$

Magnetometer.—The sketch shows a very useful and easily made form of magnetometer.



The mirror, M, with attached magnets, of a Thomson galvanometer is suspended by a single fibre of unspun silk, 6 to 10 cms. long, from a pin, S, at the top of a slot in an upright wooden bar. Near the bottom the slot is enlarged into a hole wide enough to contain the mirror without contact. The hole is closed by a lens in front

and by a strip of glass behind, which also covers the slot. The wooden upright is fixed to a horizontal wooden plate furnished with three levelling screws. The deflection is read in the usual way by means of a lamp and scale.

Lines of Force.—A magnetic field may be represented by lines, whose direction is everywhere that of the resultant magnetic force. If 4π lines of force be conceived to start from each unit pole, the lines will be everywhere so spaced that H at any point of the field is numerically equal to the number of lines which cross unit area there, measured in a plane normal to the lines of force. The positive direction of lines of force is that along which a north pole would tend to move. The lines of force produced by a bar magnet are curves which extend from the N. pole to the S. pole through space, including the substance of the magnet as well as the space outside of it. If the bar has a uniform intensity of magnetisation I and a cross-section s, the total number of lines of force is $4\pi I s$. These lines may further be conceived as extending from N. to S. through the substance of the magnetised metal, so as to form closed curves. Thus there are $4\pi I$ lines extending through the metal from N. to S. per unit of section, besides those which pass from S. to N. through the metal as well as through surrounding space. Only the latter, however, are called lines of force within the metal; the resultant of the two systems of lines forms what are called *lines of induction.*

Magnetic Induction.—A material placed in a magnetic field becomes, in general, magnetic by

induction, and the number of lines of induction passing through it is different from the number of lines of force formerly present in the same space. If the number of lines passing through the material is greater than the number formerly present in the same space, the material is said to be *paramagnetic;* if less, *diamagnetic.* In iron, which is very strongly paramagnetic, the number of lines is sometimes increased 10,000 times, or even more. The total number of lines passing through the material at any place per square centimetre of cross-section normal to the lines is the measure of the magnetic *induction* there, and is denoted by B. B consists of the lines $4\pi I$ named above, together with H, the field then in action, these being compounded with due regard to their direction:—

$$B = 4\pi I + H.^*$$

Suppose an indefinitely narrow crevasse to be cut across the magnetised piece at right angles to the direction of magnetisation, then the number of lines of force crossing this crevasse per square centimetre is B. Suppose a hole of indefinitely small bore to be drilled through the magnetised piece in the direction of magnetisation, then the number of lines of force in this hole per square centimetre of its sectional area is H.

Magnetic Permeability and Susceptibility.—When an induction, B, or an intensity of mag-

* This is a vector equation, and is to be understood in the usual algebraical sense only when I and H have the same direction.

netisation, I, is caused by the application of a magnetising force, H, the ratio $\frac{B}{H}$ is μ, the magnetic *permeability*, and the ratio $\frac{I}{H}$ is κ, the magnetic *susceptibility*, and

$$\mu = 4\pi\kappa + 1.$$

In paramagnetic substances κ is positive, and μ greater than 1. In diamagnetic substances κ is negative, but never numerically large enough to make μ negative. In iron and other strongly paramagnetic substances μ and κ are not constant, but depend on the actual and previous values of the field, H, as well as upon the specific quality of the specimen.

In measuring the magnetic permeability of a substance the specimen must be of such a form that the magnetisation can be made approximately uniform, and the field determinate. In dealing with iron or steel a short bar arranged as the core of an electro-magnet does not answer for absolute measurements, since the magnetising force at any point is due partly to the magnetising solenoid and partly to the ends of the bar itself. The influence of the ends makes H vary along the bar, and prevents the magnetisation from being at all uniform. But if the length of the bar is very great, say 300 or 400 times its diameter, the influence of the ends becomes negligible throughout the greater part of the length, and this form serves well for experiments on magnetic permeability and susceptibility. Another plan, used by Stoletow

and Rowland, is to employ a ring-shaped electromagnet, which has no ends to influence the field.

Magnetic Field produced by Current in Circular Conductor.—A current C (*c.g.s.* units) in a circular conductor, whose section is very small compared with its radius, r, produces at the centre a magnetic force, H, normal to the plane of the conductor, and equal to $\frac{2\pi C}{r}$. If the conductor is a coil of N turns, the force is $\frac{2\pi C N}{r}$. At any point on the axis, distant x from the plane of the coil, the force still acts along the axis, and is equal to $\frac{2\pi C N r^2}{(r^2+x^2)^{\frac{3}{2}}}$.

In a long solenoid, consisting of parallel turns uniformly wound, and of the same radius, the force, H, at all points within the solenoid except near the ends, is very nearly uniform, parallel to the axis, and equal to $4\pi C n$, where n is the number of turns per centimetre of the length of the solenoid. This may be written—

$$H = 1{\cdot}257 \times \text{ampere-turns per centimetre.}$$

Measurement of the Induction in, and Susceptibility of, Iron or Steel (*Ballistic Method*).—Take a wire or rod of the metal to be tested, of uniform section and quality, and not less than 300 times longer than its greatest width. Wind on it a uniform magnetising solenoid of n turns per centimetre, and slip over that to a central position a short induction-coil, which is con-

nected by twisted leading wires with a ballistic mirror galvanometer. Make a current, C, through the magnetising solenoid. This produces on the rod a magnetising force, H, equal to $4\pi C n$, and causes a transient current in the ballistic galvanometer, which gives a throw, D, proportional to $N s B$, where B is the induction in the rod, s its area of section, and N the number of turns in the induction-coil. To interpret the throw of the ballistic galvanometer, have in its circuit, in addition to the above induction coil, a second and much larger induction-coil, of N_1 turns and area s_1, wound on a light frame (which may conveniently be a hollow wooden rectangle), and laid on a horizontal table. When this coil is quickly turned over a transient current is induced, which gives a throw, D_1, of the galvanometer, proportional to $2 N_1 s_1 V_E$, where V_E is the vertical component of the earth's magnetic force, or H multiplied by the tangent of the dip. Then,

$$B = \frac{2 N_1 s_1 V_E D}{N s D_1}; \qquad H = 4\pi C n;$$

$$I = \frac{B - H}{4\pi} = \frac{N_1 s_1 V_E D}{2\pi N s D_1} - C n.$$

B may also be measured, after the rod has become magnetised, by suddenly slipping off the induction-coil, when a transient current is induced in it, proportional to $N s B$. In dealing with iron, however, this method requires much caution, as the slightest mechanical disturbance affects the magnetisation very greatly. This

method is well suited for the measurement of B at the centre or at any part of the length of a *permanent* bar magnet. The induction coil is to be slipped over the rod up to the place where B is to be determined, allowed to remain there until the galvanometer needle comes to rest, and then suddenly slipped off, when the throw of the galvanometer is to be observed.

Measurement of Strong Magnetic Fields.—The same method has been used by Rowland to measure strong magnetic fields, and serves well to investigate the field between the poles of a dynamo. Put a small induction coil (in circuit with a ballistic galvanometer) at the place where H is to be measured, and with its plane at right angles to the direction of H. Then suddenly withdraw it to a position where the magnetic field is relatively insensible. The throw of the galvanometer is proportional to N s H, and is to be compared with the throw caused by turning over a large coil in the earth's vertical field as before. For other methods, see A. Gray's *Absolute Measurements in Electricity and Magnetism*, chap. xi.

Measurement of Induction, &c., by Direct Magnetometric Method.—In place of the ballistic method described above for measuring the magnetisation of iron or steel, a convenient *direct magnetometric method* is to hang vertically a long straight wire to be magnetised, due east or west of a mirror magnetometer, with its upper end at, or a little above, the level of the magnetometer and at a horizontal distance x from it. From the tangent of the observed deflection of the magnetometer deduct the part due to the direct

electro-magnetic effect of the magnetising solenoid, which may be observed separately. Then, with the same notation as before,

$$\mathsf{I} = \frac{\mathsf{H} \tan \theta}{s\left(\frac{1}{x^2} - \frac{x}{(l^2 + x^2)^{\frac{3}{2}}}\right)} \quad \text{nearly.}$$

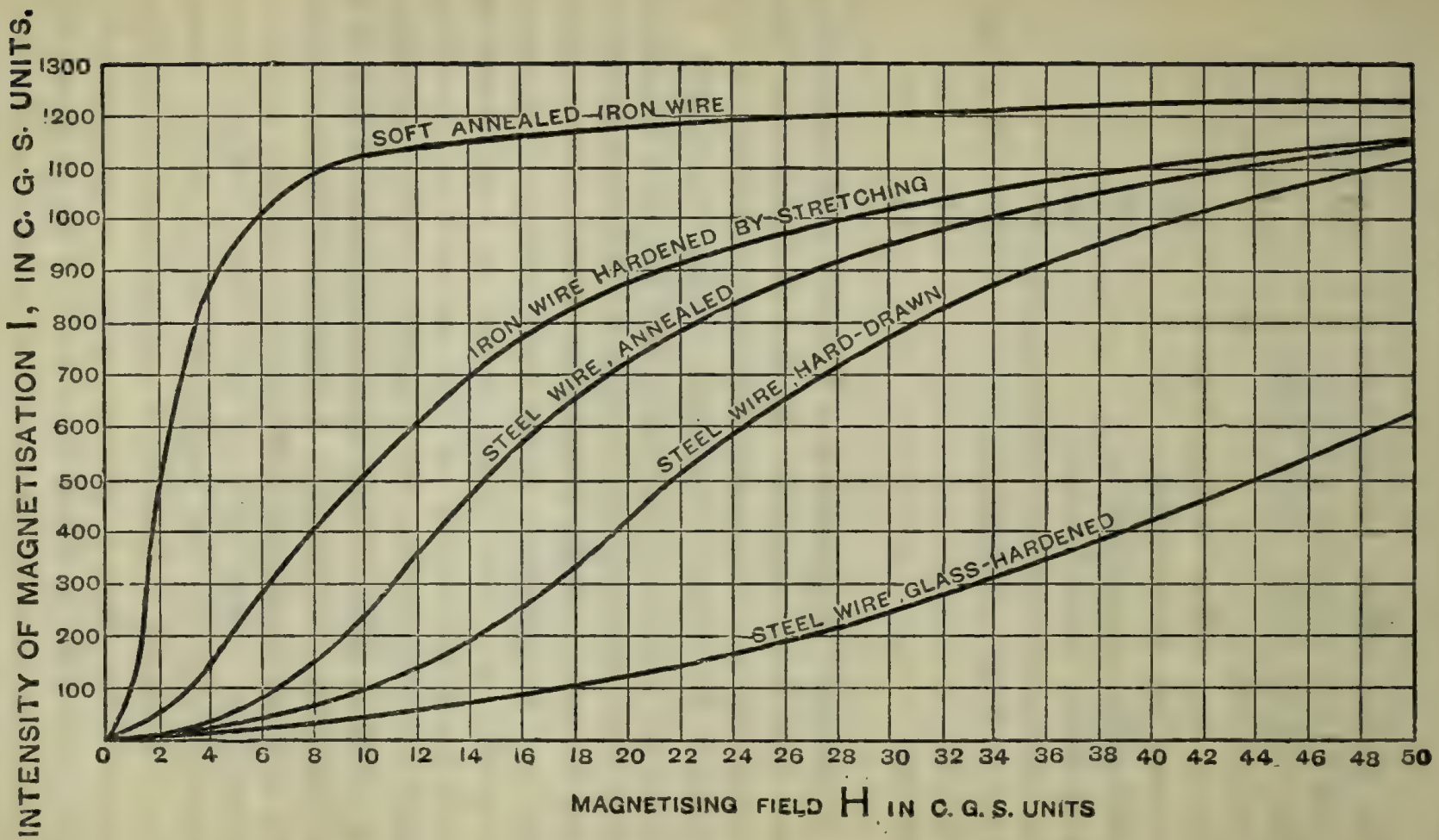
In this method the presence of the earth's field, V, must be taken account of in reckoning the magnetising force.

Curves of Magnetisation for Iron and Steel.—The figure (p. 441) shows the relation of I to H during the gradual application of magnetising force (up to H = 50) to long wires of annealed iron, to the same iron hardened by stretching, and to steel in the three conditions—annealed soft, hard-drawn, and tempered glass-hard. The curves are drawn from data supplied by the present writer's experiments. During magnetisation, κ is at first small, then increases rapidly to a maximum, after which it continues to diminish without limit as the state of "saturation" is approached. The greatest value of I easily reached in practice is about 1,300. The following table gives the maximum values reached by κ during the magnetisation of various metals:—

	Maximum value of κ.
Very soft iron wire, annealed,	280
The same, kept in a state of vibration during the application of H, . . .	1,600
Soft iron wire, annealed, .	245

The same, after being hardened by stretching, .	53	
Moderately soft iron wire, annealed, ...	200	
The same, after being hardened by stretching, .	36	
Steel wire, annealed, . .	37	
Steel wire, hard-drawn, .	25	
Pianoforte-steel wire, glass-hard,	10	
Norway iron, annealed, .	439	(Rowland)
Nickel, ...	18	do.
Cobalt, ...	11	do.

Residual Magnetism.—When a magnetising force has been applied to a substance and then completely withdrawn, the magnetisation which remains is called *residual.* The property by virtue of which some materials remain magnetic when the magnetising force is withdrawn is called *retentiveness.* Soft annealed iron shows more residual magnetism than any other substance: in it the residual magnetism is sometimes as much as 93 per cent. of the induced magnetism. Residual magnetism is less when the magnetising force is withdrawn suddenly than when it is withdrawn gradually. Changes of temperature and any mechanical disturbance reduce residual magnetism, especially in soft iron, which parts with almost all its residual magnetism when gently tapped. Residual magnetism is rapidly reduced by the application of a magnetising force opposite in direction to the force formerly applied, especially in soft iron, which parts with all its previous magnetisation on being subjected to a very weak demagnetising force. This is


INTENSITY OF MAGNETISATION I, IN C. G. S. UNITS.
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
SOFT ANNEALED IRON WIRE
IRON WIRE HARDENED BY STRETCHING
STEEL WIRE, ANNEALED
STEEL WIRE, HARD-DRAWN
STEEL WIRE GLASS-HARDENED
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50
MAGNETISING FIELD H IN C. G. S. UNITS

the reason why the soft-iron cores of short electro-magnets do not show residual magnetism —the demagnetising influence of their own ends is sufficient to reduce them to an almost neutral state. Hard iron and steel have less residual magnetism than soft iron, but hold it much more strongly, both as regards the effects of mechanical disturbance and of reverse magnetising force. Thus, a short bar of steel is able to hold a portion of its residual magnetism with some degree of permanence in spite of mechanical shocks, fluctuations of temperature, and the demagnetising field produced by its own poles. No magnet is strictly permanent.

*Measurement of H, the Horizontal Component of the Earth's Magnetic Field.**—Take a straight uniform bar of hard steel wire whose length, l, is about 8 cms., and diameter 1·5 or 2 mms., magnetise it as strongly as possible, and tap it to get the residual magnetism reduced to a nearly permanent state. Place the bar east or west of a magnetometer, and observe deflections, as in the process of measuring moment described above. Four observations of deflection should be taken, two with the bar east of the magnetometer, and two with it west of the magnetometer, the bar being turned end for end to give deflections to opposite sides, but placed with its centre at the same distance, x, from the magnetometer throughout. Take the mean of the four deflections in reckoning θ; then

$$\frac{M}{H} = \frac{\tan\theta\left(x^2 - \frac{l^2}{4}\right)^2}{2x}.$$

* For values of H, see Table, p. 404.

Next, suspend the bar by a single silk fibre, from 10 to 20 cms. long, from the cover of a glass vessel, so that it can swing in a horizontal plane within the vessel. For this purpose a double loop is to be formed at the lower end of the fibre, and the two parts of the loop spread out so as to catch the bar at two points some way apart. Place the vessel at or close to the position occupied by the magnetometer, in the former part of the observation, the magnetometer having been removed. Set the bar swinging in a horizontal plane about the fibre as axis, by bringing a magnet near it in the east or west line, and then withdrawing that. When the swing is not more than about 5° to each side, determine t, the time in seconds in which the bar makes a complete swing from the middle position to one side, over to the other side, and back to the middle position again. This is done by counting the time taken to make 30 or 40 swings, and dividing that time by the number of swings. This observation should be repeated several times and a mean taken. Finally, the deflection experiment should be gone through again to see whether the moment of the bar has altered. Let w be the weight of the bar in grammes; then

$$\mathrm{M\,H} = \frac{3{\cdot}29\, w\, l^2}{t^2},$$

and, combining this with the equation for $\frac{\mathrm{M}}{\mathrm{H}}$,

$$\mathrm{H} = \frac{2{\cdot}565\, l}{t\left(x^2 - \frac{l^2}{4}\right)} \sqrt{\frac{w\, x}{\tan\theta}}.$$

In very exact measurements of H certain corrections have to be applied, for which see Maxwell's *Electricity*, vol. ii., chap. vii.

To find the Magnetic Meridian, or direction of H, take a long straight magnetised steel wire, such as a fine knitting-needle, and suspend it from a fixed support by a single silk fibre, with a double loop at its lower end, so that it may hang in a horizontal plane just clear of the table. Protect the wire from draughts and other disturbances, and as it comes to rest lay a straight-edge on the table exactly alongside of, but not touching, the wire. The magnet can then be removed, and a line drawn on the table in the direction marked by the straight-edge.

Another method, susceptible of great accuracy, is to place a magnetometer within a large flat coil held in a vertical plane, and turn the coil in azimuth until a position is found such that the making and breaking of a current in the coil does not deflect the magnetometer. The plane of the coil then lies magnetically east and west. (*Tanakadate, Proc. R.S.E.*, 1884, p. 544.)

Determination of V_E, *the Vertical component of the Earth's Magnetic Field.*—When a dipping needle is not available, V_E may be found with considerable accuracy by either of the following methods:—

(1) Compare by a ballistic galvanometer the transient currents, D_1 and D_2, induced in a large flat coil by turning it quickly over, first on a horizontal table, and second against a vertical surface, placed in the magnetic east-west direction. Then

$$V_E = \frac{H\,D_1}{D_2}.$$

To make the comparison accurate, D_1 and D_2 should not be very unequal. They may be made nearly equal by using different numbers of turns in the coil in the two cases, and then, of course, multiplying the above expression by $\frac{n_2}{n_1}$, but care must be taken to maintain the resistance of the circuit unchanged.

(2) Take a long, straight piece of very soft, well annealed iron wire, and place it in a vertical position behind and near to a magnetometer. Let it be wound with two magnetising solenoids, one of which has n turns per cm., and extends some distance beyond the ends of the wire. Maintain a constant current, C, in this solenoid, in a direction such that the field $4\pi C n$ due to it opposes V_E. C is now to be adjusted by trial, so that $4\pi C n$ exactly balances V_E. The test of this adjustment is to make a magnetising current in the other solenoid, and gradually to reduce its strength to zero by means of a slide resistance, while its direction is rapidly reversed many times. This process, if there were no other magnetising force at work, would result in the complete demagnetisation of the iron. Hence it will give complete demagnetisation only when C is of such strength that $4\pi C n$ is equal and opposite to V_E. This resolves the measurement of V_E into the measurement of a certain current, C. A convenient slide resistance for this test is a long, vertical glass jar, filled with a dilute solution of sulphate of zinc, the terminals being zinc blocks at the bottom and top, with an intermediate contact piece consisting of another zinc block, which can be raised or lowered by means of a cord and pulley.

Measurement of weak Magnetic Fields.—Comparison of weak fields with H or with V_E may be effected by the ballistic method already described, by using sufficiently large induction coils, or by the second method just described for V_E. Or, in the case of a horizontal field whose strength is to be determined, the time τ in which a suspended magnet makes a complete swing in that field, may be observed and compared with the time t in which it swings in the field H. Then

$$\text{Field to be measured} = \frac{H\,t^2}{\tau^2}.$$

Another method of comparing magnetic fields, whether weak or strong, is to compare the sensibility of a galvanometer when its needle is directed by one field, with the sensibility of the same, or an easily comparable galvanometer, when its needle is directed by the other field. An important case is the field produced by the semicircular directing magnet of Sir W. Thomson's graded galvanometers. Let a constant current pass, and observe D_1 the deflection when H only is acting, and the platform number is n_1; then observe the deflection, D_2, produced by the same current when the field is H + X (X being the unknown field due to the magnet), and the platform number is n_2. Then

$$X = H\left(\frac{D_1\,n_2}{D_2\,n_1} - 1\right)$$

See also Gray's *Absolute Measurements*, chap. vii.

LOGARITHMIC and TRIGONOMETRIC TABLES, by J. T. BOTTOMLEY, M.A., F.R.S.E., Glasgow University.*

A logarithm is a number consisting of two parts—an integer part and a decimal. The former is called the *Index*, the latter the *Mantissa*.

RULE I.—The index of the logarithm of a number greater than unity is one less than the number of figures in the integral part of that number.

Thus, the index of 71820 is 4.
71·82 is 1.
7·182 is 0.

RULE II.—The index of the logarithm of a number less than unity is negative, and is a higher number by one than the number of zeros that follow the decimal point.

To denote that the index is negative, the sign minus is written above it.

Thus, the index of the logarithm of
0.7182 is $\bar{1}$.
Do. do. 0·007182 is $\bar{3}$.

RULE III.—**To find the mantissa of the logarithm of a given number consisting of**

* From the work under the above title, published by William Collins & Sons, Glasgow, with useful Mathematical Formulæ. The tables given here, pages 455–464, have been found very useful, and sufficiently accurate for most ordinary questions concerning the tests of submarine cables, land lines, electric lamps, &c.

four figures.—Having found the *first two* figures of the given number in the left-hand column of the table, pass along the horizontal line, and take the number in the vertical column headed by the *third* figure. Add to that number the number found in the difference columns under the *fourth* figure of the given number. The sum, with a decimal point prefixed, is the required mantissa.

EXAMPLES.—Find the mantissae corresponding to the figures 7182 and 2956 :—

718	. . . . .	8561
	2 from dif. col.	1
		·8562
295	. . . . .	4698
	6 from dif. col.	9
		·4707

RULE IV.—**To find the logarithm of a number consisting of four figures.**—Find the mantissa corresponding to the figures, and prefix the proper index. The number thus obtained is that required.

EXAMPLES— log. 71820 . . . = 4·8562
log. 7·182 . . . = 0·8562
log. 0.7182 . . . = $\bar{1}$·8562
log. 0·007182 . . = $\bar{3}$·8562

RULE V.—**To find the antilogarithm of a number, *i.e.*, the number corresponding to a given logarithm.**—Find in the table of antilogarithms, in a way similar to that indicated

in Rule III., the number corresponding to the mantissa of the given logarithm. Place a decimal point, prefixing or affixing zeros, if necessary, in the position indicated by the index of the given logarithm, as explained in Rules I. and II. The number thus obtained is that required.

EXAMPLE.—Given the logarithm 2·4708; find the antilogarithm. Corresponding to the mantissa ·4708 we find—

·470	. . . . .	2951
	8 from dif. col.	5
		2956

and hence the number whose logarithm is 2·4708, is 295·6.

The number whose logarithm is $\bar{3}$·4708, is 0·002956.

MEMORANDUM.—The number of zeros to be prefixed is one less than the negative index.

* Or **the number corresponding to a given logarithm** may be found from the table of logarithms (pp. 455–459). This is, however, not quite so correct as the method of using antilogarithms.

Look for the nearest set of figures to the mantissa in the column of logarithms, then the *first two* figures of the corresponding number are found in first column in the same horizontal line, the *third* in the top or bottom heading of same vertical column, and the *fourth* from the heading for the column of differences corresponding to the nearest difference between the logarithm found in the table and the given mantissa.

* This addition to Rule V. by authors.

Then place a decimal point, prefixing or affixing zero, if necessary, in the position indicated by the index of the given logarithm, as explained in Rules I. and II. The number thus obtained is that required.

EXAMPLES.—Given the logarithm 3·8648; find the corresponding number. The nearest figures to the mantissa ·8648 in the column of logarithms are—

	·8645	732
add	3 from dif. col. . .	5
	8648	7325

Hence the number whose logarithm is—

3·8648	. . is . .	7325·
2·8648	. . ,, . .	. 732·5
1·8648	. . ,, . .	. 73·25
·8648	. . ,, . .	. 7·325
$\bar{1}$·8648	. . ,, . .	. ·7325
$\bar{2}$·8648	. . ,, . .	. ·07325
$\bar{3}$·8648	. . ,, . .	. ·007325

To *multiply* by logarithms add the logarithms together and find the corresponding number.

EXAMPLE— 2956 × 24·29

log. 2956	. .	3·4707
log. 24·29	.	1·3854
add		4·8561 ∴ number = 71800

To *divide* by logarithms, subtract one logarithm from the other and find the corresponding number.

EXAMPLE— 71800÷2956

log. 71800 = 4·8561
log. 2956 = 3·4707

subtract 1·3854 ∴ number = 24·29

To *extract* the Root by logarithms, divide the logarithm by the index of the root and find the corresponding number.

EXAMPLE— $\sqrt{841}$

log. 841 = 2·9248
divide by 2 = 1·4624 ∴ number = 29·0

EXAMPLE— $\sqrt{5475600}$

nearest log. 5475600 = 6·7384

divide by 2 = 3·3692 ∴ number = 2340

EXAMPLE— $\sqrt[3]{729}$

log. 729 = 2·8627

divide by 3 = ·9542 ∴ number = 9·0

EXAMPLE— $\sqrt[3]{531441}$

nearest log. 531441 = 5·7254

divide by 3 = 1·9085 ∴ number = 81

To *raise a number to any power*, multiply the logarithm by the index of the power, and find the corresponding number.

EXAMPLE— 29^2

log. 29 = 1·4624

multiply by 2 = 2·9248 ∴ number = 841

RULE VI.—**To find the natural sine, cosine, or tangent of an angle, less than 90°, given in degrees and minutes.**—In the left-hand column of the proper table find the given nnmber of degrees. Pass along the corresponding horizontal line, and take the number in the vertical column, headed by the number of minutes lower than and nearest to the given number of minutes. Taking the difference between this number and the given number of minutes, enter the difference columns in the same horizontal line, and take out the number in the vertical column headed by that difference. In the case of the sine and tangent, add the two numbers thus obtained. In the case of the cosine, the number found in the difference column is to be *subtracted*. The result will be the natural sine, cosine, or tangent sought.

NOTE.—In the tables of natural sines and cosines the decimal points are omitted. In the table of natural tangents the decimal points and the whole numbers that precede them are omitted in all the columns but that headed 0′, except in the case of a few degrees at the last. Here, also, the differences are not given, because, owing to the rapidity of changes in the value of

the tangents, the method employed for displaying the differences ceases to be advantageous. The occurrence of a marked figure, such as 2, in the tables, indicates that the whole number of the column under 0′ has changed, and that the whole number in the next horizontal line is to be used.

EXAMPLE.—Find the sine and the cosine of 25° 17′, and the tangent of 55° 27′.

From table of sines,	25° 12′	. . . . .	4258
	5′	. . . . .	13
	sin. 25° 17′	=	·4271
From table of cosines,	25° 12′	. . . . .	9048
	5′	. . . . .	6
	cos. 25° 17′	=	·9042
From table of tangents,	55° 24′	. . . .	1·4496
	3′	. . . . .	27
	tan. 55° 27′	=	1·4523

RULE VII.—**To find the cotangent of an angle less than 90°, given in degrees and minutes.**—The tangent of the complement of a given angle is the cotangent of the given angle.

EXAMPLE— cot. 28° 16′ = tan. 61° 44 = 1·8598

RULE VIII.—**To find the angle in degrees and minutes corresponding to any given sine, cosine, tangent, or cotangent.**—Find within the proper table the nearest number to that

given, interpolating, if necessary, by means of the difference columns; and by a process the converse of that indicated in Rules VI. and VII., determine the degrees and minutes corresponding to the given sine, cosine, tangent, or cotangent.

EXAMPLE—Find the angle of which 0·3495 is the sine.

	0·3495		
From table of sines,	3486	. .	20° 24′
From difference col.	9	. .	3′ nearly.
	0·3495 = sin. 20° 27′		

Base of *napierian* or *hyperbolic* logarithms, $\varepsilon = 2{\cdot}71828$.
To convert *common* into *hyperbolic* logarithms, $\times\ 2{\cdot}3026$.
To convert *hyperbolic* into *common* ,, $\times\ 0{\cdot}43429$.

Unit angle (arc = radius) = 57° ·2958 = 57° 17′ 45″.

Binomial Theorem—

$$(1 \pm e)^n = 1 \pm ne + \frac{n \cdot \overline{n-1}}{1 \cdot 2} e^2 \pm \frac{n \cdot \overline{n-1} \cdot \overline{n-2}}{1 \cdot 2 \cdot 3} e^3 + \&c.$$

When ne is so small that its square and higher powers may be neglected $(1 \pm e)^n$ is approximately $(1 \pm ne)$. Ex. $e = {\cdot}01$; $(1 + {\cdot}01)^2$ — is approximately $= 1{\cdot}02$.

Compound Interest Law.
To find the value of $(1 + p)^n$. Let it equal S. Then

$$\log._{10} S = n \log._{10} (1 + p),$$

Ex. rate $p = 0{\cdot}05 \div 100$ $(\frac{1}{20}\,{}^{\circ}/_{\circ})$, $n = 1383$ makes $S = 2$ (capital doubled).

ARRANGED BY J. T. BOTTOMLEY, M.A., F.R.S.E.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9863	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4
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·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
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·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

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·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
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·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
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·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
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·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
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·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
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·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4 92	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
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·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5
0°	0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	0349	0366	0384	0401	0419	0436	0454	0471	0488	0506	3	6	9	12	15
3	0523	0541	0558	0576	0593	0610	0628	0645	0663	0680	3	6	9	12	15
4	0698	0715	0732	0750	0767	0785	0802	0819	0837	0854	3	6	9	12	15
5	0871	0889	0906	0924	0941	0958	0976	0993	1011	1028	3	6	9	12	14
6	1045	1063	1080	1097	1115	1132	1149	1167	1184	1201	3	6	9	12	14
7	1219	1236	1253	1271	1288	1305	1323	1340	1357	1374	3	6	9	12	14
8	1392	1409	1426	1444	1461	1478	1495	1513	1530	1547	3	6	9	12	14
9	1564	1582	1599	1616	1633	1650	1668	1685	1702	1719	3	6	9	12	14
10	1736	1754	1771	1788	1805	1822	1840	1857	1874	1891	3	6	9	12	14
11	1908	1925	1942	1959	1977	1994	2011	2028	2045	2062	3	6	9	11	14
12	2079	2096	2113	2130	2147	2164	2181	2198	2215	2232	3	6	9	11	14
13	2250	2267	2284	2300	2317	2334	2351	2368	2385	2402	3	6	8	11	14
14	2419	2436	2453	2470	2487	2504	2521	2538	2554	2571	3	6	8	11	14
15	2588	2605	2622	2639	2656	2672	2689	2706	2723	2740	3	6	8	11	14
16	2756	2773	2790	2807	2823	2840	2857	2874	2890	2907	3	6	8	11	14
17	2924	2940	2957	2974	2990	3007	3024	3040	3057	3074	3	6	8	11	14
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5
18°	3090	3107	3123	3140	3156	3173	3190	3206	3223	3239	3	6	8	11	14
19	3256	3272	3289	3305	3322	3338	3355	3371	3387	3404	3	5	8	11	14
20	3420	3437	3453	3469	3486	3502	3518	3535	3551	3567	3	5	8	11	14
21	3584	3600	3616	3633	3649	3665	3681	3697	3714	3730	3	5	8	11	14
22	3746	3762	3778	3795	3811	3827	3843	3859	3875	3891	3	5	8	11	14
23	3907	3923	3939	3955	3971	3987	4003	4019	4035	4051	3	5	8	11	14
24	4067	4083	4099	4115	4131	4147	4163	4179	4195	4210	3	5	8	11	13
25	4226	4242	4258	4274	4289	4305	4321	4337	4352	4368	3	5	8	11	13
26	4384	4399	4415	4431	4446	4462	4478	4493	4509	4524	3	5	8	10	13
27	4540	4555	4571	4586	4602	4617	4633	4648	4664	4679	3	5	8	10	13
28	4695	4710	4726	4741	4756	4772	4787	4802	4818	4833	3	5	8	10	13
29	4848	4863	4879	4894	4909	4924	4939	4955	4970	4985	3	5	8	10	13
30	5000	5015	5030	5045	5060	5075	5090	5105	5120	5135	3	5	8	10	13
31	5150	5165	5180	5195	5210	5225	5240	5255	5270	5284	2	5	7	10	12
32	5299	5314	5329	5344	5358	5373	5388	5402	5417	5432	2	5	7	10	12
33	5446	5461	5476	5490	5505	5519	5534	5548	5563	5577	2	5	7	10	12
34	5592	5606	5621	5635	5650	5664	5678	5693	5707	5721	2	5	7	10	12
35	5736	5750	5764	5779	5793	5807	5821	5835	5850	5864	2	5	7	9	12
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5
36°	5878	5892	5906	5920	5934	5948	5962	5976	5990	6004	2	5	7	9	12
37	6018	6032	6046	6060	6074	6088	6101	6115	6129	6143	2	5	7	9	12
38	6157	6170	6184	6198	6211	6225	6239	6252	6266	6280	2	5	7	9	11
39	6293	6307	6320	6334	6347	6361	6374	6388	6401	6414	2	4	7	9	11
40	6428	6441	6455	6468	6481	6494	6508	6521	6534	6547	2	4	7	9	11
41	6561	6574	6587	6600	6613	6626	6639	6652	6665	6678	2	4	7	9	11
42	66 1	6704	6717	6730	6743	6756	6769	6782	6794	6807	2	4	6	9	11
43	6820	6833	6845	6858	6871	6884	6896	6909	6921	6934	2	4	6	8	11
44	6947	6959	6972	6984	6997	7009	7022	7034	7046	7059	2	4	6	8	10
45	7071	7083	7096	7108	7120	7133	7145	7157	7169	7181	2	4	6	8	10
46	7193	7206	7218	7230	7242	7254	7266	7278	7290	7302	2	4	6	8	10
47	7314	7325	7337	7349	7361	7373	7385	7396	7408	7420	2	4	6	8	10
48	7431	7443	7455	7466	7478	7490	7501	7513	7524	7536	2	4	6	8	10
49	7547	7558	7570	7581	7593	7604	7615	7627	7638	7649	2	4	6	8	9
50	7660	7672	7683	7694	7705	7716	7727	7738	7749	7760	2	4	6	7	9
51	7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	2	4	5	7	9
52	7880	7891	7902	7912	7923	7934	7944	7955	79 5	7976	2	4	5	7	9
53	7986	7997	8007	8018	8028	8039	8049	8059	8070	8080	2	3	5	7	9
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5
54°	8090	8100	8111	8121	8131	8141	8151	8161	8171	8181	2	3	5	7	8
55	8192	8202	8211	8221	8231	8241	8251	8261	8271	8281	2	3	5	7	8
56	8290	8300	8310	8320	8329	8339	8348	8358	8368	8377	2	3	5	6	8
57	8387	8396	8406	8415	8425	8434	8443	8453	8462	8471	2	3	5	6	8
58	8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	2	3	5	6	8
59	8572	8581	8590	8599	8607	8616	8625	8634	8643	8652	1	3	4	6	7
60	8660	8669	8678	8686	8695	8704	8712	8721	8729	8738	1	3	4	6	7
61	8746	8755	8763	8771	8780	8788	8796	8805	8813	8821	1	3	4	6	7
62	8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	1	3	4	5	7
63	8910	8918	8926	8934	8942	8949	8957	8965	8973	8980	1	3	4	5	6
64	8988	8996	9003	9011	9018	9026	9033	9041	9048	9056	1	3	4	5	6
65	9063	9070	9078	9085	9092	9100	9107	9114	9121	9128	1	2	4	5	6
66	9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	1	2	3	5	6
67	9205	9212	9219	9225	9232	9239	9245	9252	9259	9265	1	2	3	4	6
68	9272	9278	9285	9291	9298	9304	9311	9317	9323	9330	1	2	3	4	5
69	9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	1	2	3	4	5
70	9397	9403	9409	9415	9421	9426	9432	9438	9444	9449	1	2	3	4	5
71	9455	9461	9466	9472	9478	9483	9489	9494	9500	9505	1	2	3	4	5
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5

.	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5
72°	9511	9516	9521	9527	9532	9537	9542	9548	9553	9558	1	2	3	4	4
73	9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	1	2	2	3	4
74	9613	9617	9622	9627	9632	9636	9641	9646	9650	9655	1	2	2	3	4
75	9659	9664	9668	9673	9677	9681	9686	9690	9694	9699	1	1	2	3	4
76	9703	9707	9711	9716	9720	9724	9728	9732	9736	9740	1	1	2	3	3
77	9744	9748	9751	9755	9759	9763	9767	9770	9774	9778	1	1	2	3	3
78	9781	9785	9789	9792	9796	9799	9803	9806	9810	9813	1	1	2	2	3
79	9816	9820	9823	9826	9829	9833	9836	9839	9842	9845	1	1	2	2	3
80	9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	0	1	1	2	2
81	9877	9880	9882	9885	9888	9890	9893	9895	9898	9900	0	1	1	2	2
82	9903	9905	9907	9910	9912	9914	9917	9919	9921	9923	0	1	1	2	2
83	9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	0	1	1	1	2
84	9945	9947	9949	9951	9952	9954	9956	9957	9959	9960	0	1	1	1	2
85	9962	9963	9965	9966	9968	9969	9971	9972	9973	9974	0	0	1	1	1
86	9976	9977	9978	9979	9980	9981	9982	9983	9984	9985	0	0	1	1	1
87	9986	9987	9988	9989	9990	9990	9991	9992	9993	9993	0	0	0	1	1
88	9994	9995	9995	9996	9996	9997	9997	9997	9998	9998	0	0	0	0	0
89	9998	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	0	0	0	0
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5
0°	1·000	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	0	0	0	0
1	9998	9998	9998	9997	9997	9997	9996	9996	9995	9995	0	0	0	0	0
2	9994	9993	9993	9992	9991	9990	9990	9989	9988	9987	0	0	0	1	1
3	9986	9985	9984	9983	9982	9981	9980	9979	9978	9977	0	0	1	1	1
4	9976	9974	9973	9972	9971	9969	9968	9966	9965	9963	0	0	1	1	1
5	9962	9960	9959	9957	9956	9954	9952	9951	9949	9947	0	1	1	1	2
6	9945	9943	9942	9940	9938	9936	9934	9932	9930	9928	0	1	1	1	2
7	9925	9923	9921	9919	9917	9914	9912	9910	9907	9905	0	1	1	2	2
8	9903	9900	9898	9895	9893	9890	9888	9885	9882	9880	0	1	1	2	2
9	9877	9874	9871	9869	9866	9863	9860	9857	9854	9851	0	1	1	2	2
10	9848	9845	9842	9839	9836	9833	9829	9826	9823	9820	1	1	2	2	3
11	9816	9813	9810	9806	9803	9799	9796	9792	9789	9785	1	1	2	2	3
12	9781	9778	9774	9770	9767	9763	9759	9755	9751	9748	1	1	2	3	3
13	9744	9740	9736	9732	9728	9724	9720	9715	9711	9707	1	1	2	3	3
14	9703	9699	9694	9690	9686	9681	9677	9673	9668	9664	1	1	2	3	4
15	9659	9655	9650	9646	9641	9636	9632	9627	9622	9617	1	2	2	3	4
16	9613	9608	9603	9598	9593	9588	9583	9578	9573	9568	1	2	2	3	4
17	6563	9558	9553	9548	9542	9537	9532	9527	9521	9516	1	2	3	4	4
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5

N.B.*—Numbers in difference-columns to be subtracted, not added.—*See Rules.

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5
18°	9511	9505	9500	9494	9489	9483	9478	9472	9466	9461	1	2	3	4	5
19	9455	9449	9444	9438	9432	9426	9421	9415	9409	9403	1	2	3	4	5
20	9397	9391	9385	9379	9373	9367	9361	9354	9348	9342	1	2	3	4	5
21	9336	9330	9323	9317	9311	9304	9298	9291	9285	9278	1	2	3	4	5
22	9272	9265	9259	9252	9245	9239	9232	9225	9219	9212	1	2	3	4	6
23	9205	9198	9191	9184	9178	9171	9164	9157	9150	9143	1	2	3	5	6
24	9135	9128	9121	9114	9107	9100	9092	9085	9078	9070	1	2	4	5	6
25	9063	9056	9048	9041	9033	9026	9018	9011	9003	8996	1	3	4	5	6
26	8988	8980	8973	8965	8957	8949	8942	8934	8926	8918	1	3	4	5	6
27	8910	8902	8894	8886	8878	8870	8862	8854	8846	8838	1	3	4	5	7
28	8829	8821	8813	8805	8796	8788	8780	8771	8763	8755	1	3	4	6	7
29	8746	8738	8729	8721	8712	8704	8695	8686	8678	8669	1	3	4	6	7
30	8660	8652	8643	8634	8625	8616	8607	8599	8590	8581	1	3	4	6	7
31	8572	8563	8554	8545	8536	8526	8517	8508	8499	8490	2	3	5	6	8
32	8480	8471	8462	8453	8443	8434	8425	8415	8406	8396	2	3	5	6	8
33	8387	8377	8368	8358	8348	8339	8329	8320	8310	8300	2	3	5	6	8
34	8290	8281	8271	8261	8251	8241	8231	8221	8211	8202	2	3	5	7	8
35	8192	8181	8171	8161	8151	8141	8131	8121	8111	8100	2	3	5	7	8
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5
36°	8090	8080	8070	8059	8049	8039	8028	8018	8007	7997	2	3	5	7	9
37	7986	7976	7965	7955	7944	7934	7923	7912	7902	7891	2	4	5	7	9
38	7880	7869	7859	7848	7837	7826	7815	7804	7793	7782	2	4	5	7	9
39	7771	7760	7749	7738	7727	7716	7705	7694	7683	7672	2	4	6	7	9
40	7660	7649	7638	7627	7615	7604	7593	7581	7570	7559	2	4	6	8	9
41	7547	7536	7524	7513	7501	7490	7478	7466	7455	7443	2	4	6	8	10
42	7431	7420	7408	7396	7385	7373	7361	7349	7337	7325	2	4	6	8	10
43	7314	7302	7290	7278	7266	7254	7242	7230	7218	7206	2	4	6	8	10
44	7193	7181	7169	7157	7145	7133	7120	7108	7096	7083	2	4	6	8	10
45	7071	7059	7046	7034	7022	7009	6997	6984	6972	6959	2	4	6	8	10
46	6947	6934	6921	6909	6896	6884	6871	6858	6845	6833	2	4	6	8	11
47	6820	6807	6794	6782	6769	6756	6743	6730	6717	6704	2	4	6	9	11
48	6691	6678	6665	6652	6639	6626	6613	6600	6587	6574	2	4	7	9	11
49	6561	6547	6534	6521	6508	6494	6481	6468	6455	6441	2	4	7	9	11
50	6428	6414	6401	6388	6374	6361	6347	6334	6320	6307	2	4	7	9	11
51	6293	6280	6266	6252	6239	6225	6211	6198	6184	6170	2	5	7	9	11
52	6157	6143	6129	6115	6101	6088	6074	6060	6046	6032	2	5	7	9	12
53	6018	6004	5990	5976	5962	5948	5934	5920	5906	5892	2	5	7	9	12
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5
54°	5878	5864	5850	5835	5821	5807	5793	5779	5764	5750	2	5	7	9	12
55	5736	5721	5707	5693	5678	5664	5650	5635	5621	5606	2	5	7	10	12
56	5592	5577	5563	5548	5534	5519	5505	5490	5476	5461	2	5	7	10	12
57	5446	5432	5417	5402	5388	5373	5358	5344	5329	5314	2	5	7	10	12
58	5299	5284	5270	5255	5240	5225	5210	5195	5180	5165	2	5	7	10	12
59	5150	5135	5120	5105	5090	5075	5060	5045	5030	5015	3	5	8	10	13
60	5000	4985	4970	4955	4939	4924	4909	4894	4879	4863	3	5	8	10	13
61	4848	4833	4818	4802	4787	4772	4756	4741	4726	4710	3	5	8	10	13
62	4695	4679	4664	4648	4633	4617	4602	4586	4571	4555	3	5	8	10	13
63	4540	4524	4509	4493	4478	4462	4446	4431	4415	4399	3	5	8	10	13
64	4384	4368	4352	4337	4321	4305	4289	4274	4258	4242	3	5	8	11	13
65	4226	4210	4195	4179	4163	4147	4131	4115	4099	4083	3	5	8	11	13
66	4067	4051	4035	4019	4003	3987	3971	3955	3939	3923	3	5	8	11	14
67	3907	3891	3875	3859	3843	3827	3811	3795	3778	3762	3	5	8	11	14
68	3746	3730	3714	3697	3681	3665	3649	3633	3616	3600	3	5	8	11	14
69	3584	3567	3551	3535	3518	3502	3486	3469	3453	3437	3	5	8	11	14
70	3420	3404	3387	3371	3355	3338	3322	3305	3289	3272	3	5	8	11	14
71	3256	3239	3223	3206	3190	3173	3156	3140	3123	3107	3	6	8	11	14
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5
72°	3090	3074	3057	3040	3024	3007	2990	2974	2957	2940	3	6	8	11	14
73	2924	2907	2890	2874	2857	2840	2823	2807	2790	2773	3	6	8	11	14
74	2756	2740	2723	2706	2689	2672	2656	2639	2622	2605	3	6	8	11	14
75	2588	2571	2554	2538	2521	2504	2487	2470	2453	2436	3	6	8	11	14
76	2419	2402	2385	2368	2351	2334	2317	2300	2284	2267	3	6	8	11	14
77	2250	2233	2215	2198	2181	2164	2147	2130	2113	2096	3	6	9	11	14
78	2079	2062	2045	2028	2011	1994	1977	1959	1942	1925	3	6	9	11	14
79	1908	1891	1874	1857	1840	1822	1805	1788	1771	1754	3	6	9	12	14
80	1736	1719	1702	1685	1668	1650	1633	1616	1599	1582	3	6	9	12	14
81	1564	1547	1530	1513	1495	1478	1461	1444	1426	1409	3	6	9	12	14
82	1392	1374	1357	1340	1323	1305	1288	1271	1253	1236	3	6	9	12	14
83	1219	1201	1184	1167	1149	1132	1115	1097	1080	1063	3	6	9	12	14
84	1045	1028	1011	0993	0976	0958	0941	0924	0906	0889	3	6	9	12	14
85	0872	0854	0837	0819	0802	0785	0767	0750	0732	0715	3	6	9	12	15
86	0698	0680	0663	0645	0628	0610	0593	0576	0558	0541	3	6	9	12	15
87	0523	0506	0488	0471	0454	0436	0419	0401	0384	0366	3	6	9	12	15
88	0349	0332	0314	0297	0279	0262	0244	0227	0209	0192	3	6	9	12	15
89	0175	0157	0140	0122	0105	0087	0070	0052	0035	0017	3	6	9	12	15
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5
0°	·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	14
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	·0349	0367	0384	0402	0419	0437	0454	0472	0489	0507	3	6	9	12	15
3	·0524	0542	0559	0577	0594	0612	0629	0647	0664	0682	3	6	9	12	15
4	·0699	0717	0734	0752	0769	0787	0805	0822	0840	0857	3	6	9	12	15
5	·0875	0892	0910	0928	0945	0963	0981	0998	1016	1033	3	6	9	12	15
6	·1051	1069	1086	1104	1122	1139	1157	1175	1192	1210	3	6	9	12	15
7	·1228	1246	1263	1281	1299	1317	1334	1352	1370	1388	3	6	9	12	15
8	·1405	1423	1441	1459	1477	1495	1512	1530	1548	1566	3	6	9	12	15
9	·1584	1602	1620	1638	1655	1673	1691	1709	1727	1745	3	6	9	12	15
10	·1763	1781	1799	1817	1835	1853	1871	1890	1908	1926	3	6	9	12	15
11	·1944	1962	1980	1998	2016	2035	2053	2071	2089	2107	3	6	9	12	15
12	·2126	2144	2162	2180	2199	2217	2235	2254	2272	2290	3	6	9	12	15
13	·2309	2327	2345	2364	2382	2401	2419	2438	2456	2475	3	6	9	12	15
14	·2493	2512	2530	2549	2568	2586	2605	2623	2642	2661	3	6	9	12	16
15	·2679	2698	2717	2736	2754	2773	2792	2811	2830	2849	3	6	9	13	16
16	·2867	2886	2905	2924	2943	2962	2981	3000	3019	3038	3	6	9	13	16
17	·3057	3076	3096	3115	3134	3153	3172	3191	3211	3230	3	6	10	13	16
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5
18°	·3249	3269	3288	3307	3327	3346	3365	3385	3404	3424	3	6	10	13	16
19	·3443	3463	3482	3502	3522	3541	3561	3581	3600	3620	3	6	10	13	17
20	·3640	3659	3679	3699	3719	3739	3759	3779	3799	3819	3	7	10	13	17
21	·3839	3859	3879	3899	3919	3939	3959	3979	4000	4020	3	7	10	13	17
22	·4040	4061	4081	4101	4122	4142	4163	4183	4204	4224	3	7	10	14	17
23	·4245	4265	4286	4307	4327	4348	4369	4390	4411	4431	3	7	10	14	17
24	·4452	4473	4494	4515	4536	4557	4578	4599	4621	4642	4	7	10	14	18
25	·4663	4684	4706	4727	4748	4770	4791	4813	4834	4856	4	7	11	14	18
26	·4877	4899	4921	4942	4964	4986	5008	5029	5051	5073	4	7	11	15	18
27	·5095	5117	5139	5161	5184	5206	5228	5250	5272	5295	4	7	11	15	18
28	·5317	5340	5362	5384	5407	5430	5452	5475	5498	5520	4	8	11	15	19
29	·5543	5566	5589	5612	5635	5658	5681	5704	5727	5750	4	8	12	15	19
30	·5774	5797	5820	5844	5867	5890	5914	5938	5961	5985	4	8	12	16	20
31	·6009	6032	6056	6080	6104	6128	6152	6176	6200	6224	4	8	12	16	20
32	·6249	6273	6297	6322	6346	6371	6395	6420	6445	6469	4	8	12	16	20
33	·6494	6519	6544	6569	6594	6619	6644	6669	6694	6720	4	8	13	17	21
34	·6745	6771	6796	6822	6847	6873	6899	6924	6950	6976	4	9	13	17	21
35	·7002	7028	7054	7080	7107	7133	7159	7186	7212	7239	4	9	13	18	22
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5
36°	·7265	7292	7319	7346	7373	7400	7427	7454	7481	7508	5	9	14	18	23
37	·7536	7563	7590	7618	7646	7673	7701	7729	7757	7785	5	9	14	18	23
38	·7813	7841	7869	7898	7926	7954	7983	8012	8040	8069	5	10	14	19	24
39	·8098	8127	8156	8185	8214	8243	8273	8302	8332	8361	5	10	15	20	24
40	·8391	8421	8451	8481	8511	8541	8571	8601	8632	8662	5	10	15	20	25
41	·8693	8724	8754	8785	8816	8847	8878	8910	8941	8972	5	10	16	21	26
42	·9004	9036	9067	9099	9131	9163	9195	9228	9260	9293	5	11	16	21	27
43	·9325	9358	9391	9424	9457	9490	9523	9556	9590	9623	6	11	17	22	28
44	·9657	9691	9725	9759	9793	9827	9861	9896	9930	9965	6	11	17	23	29
45	1·0000	0035	0070	0105	0141	0176	0212	0247	0283	0319	6	12	18	24	30
46	1·0355	0392	0428	0464	0501	0538	0575	0612	0649	0686	6	12	18	25	31
47	1·0724	0761	0799	0837	0875	0913	0951	0990	1028	1067	6	13	19	25	32
48	1·1106	1145	1184	1224	1263	1303	1343	1383	1423	1463	7	13	20	26	33
49	1·1504	1544	1585	1626	1667	1708	1750	1792	1833	1875	7	14	21	28	34
50	1·1918	1960	2002	2045	2088	2131	2174	2218	2261	2305	7	14	22	29	36
51	1·2349	2393	2437	2482	2527	2572	2617	2662	2708	2753	8	15	23	30	38
52	1·2799	2846	2892	2938	2985	3032	3079	3127	3175	3222	8	16	23	31	39
53	1·3270	3319	3367	3416	3465	3514	3564	3613	3663	3713	8	16	25	33	41
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5
54°	1·3764	3814	3865	3916	3968	4019	4071	4124	4176	4229	9	17	26	34	43
55	1·4281	4335	4388	4442	4496	4550	4605	4659	4715	4770	9	18	27	36	45
56	1·4826	4882	4938	4994	5051	5108	5166	5224	5282	5340	10	19	29	38	48
57	1·5399	5458	5517	5577	5637	5697	5757	5818	5880	5941	10	20	30	40	50
58	1·6003	6066	6128	6191	6255	6319	6383	6447	6512	6577	11	21	32	43	53
59	1·6643	6709	6775	6842	6909	6977	7045	7113	7182	7251	11	23	34	45	56
60	1·7321	7391	7461	7532	7603	7675	7747	7820	7893	7966	12	24	36	48	60
61	1·8040	8115	8190	8265	8341	8418	8495	8572	8650	8728	13	26	38	51	64
62	1·8807	8887	8967	9047	9128	9210	9292	9375	9458	9542	14	27	41	55	68
63	1·9626	9711	9797	9883	9970	$\bar{0}057$	$\bar{0}145$	$\bar{0}233$	$\bar{0}323$	$\bar{0}413$	15	29	44	58	73
64	2·0503	0594	0686	0778	0872	0965	1060	1155	1251	1348	16	31	47	63	78
65	2·1445	1543	1642	1742	1842	1943	2045	2148	2251	2355	17	34	51	68	85
66	2·2460	2566	2673	2781	2889	2998	3109	3220	3332	3445	18	37	55	74	92
67	2·3559	3673	3789	3906	4023	4142	4262	4383	4504	4627	20	40	60	79	99
68	2·4751	4876	5002	5129	5257	5386	5517	5649	5782	5916	22	43	65	87	108
69	2·6051	6187	6325	6464	6605	6746	6889	7034	7179	7326	24	47	71	95	118
70	2·7475	7625	7776	7929	8083	8239	8397	8556	8716	8878	26	52	78	104	130
71	2·9042	9208	9375	9544	9714	9887	$\bar{0}061$	$\bar{0}237$	$\bar{0}415$	$\bar{0}595$	29	58	87	115	144
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1	2	3	4	5
72°	3·0777	0961	1146	1334	1524	1716	1910	2106	2305	2506	32	64	96	129	161
73	3·2709	2914	3122	3332	3544	3759	3977	4197	4420	4646	36	72	108	144	180
74	3·4874	5105	5339	5576	5816	6059	6305	6554	6806	7062	41	81	122	162	203
75	3·7321	7583	7848	8118	8391	8667	8947	9232	9520	9812	46	93	139	186	232
76	4·0108	0408	0713	1022	1335	1653	1976	2303	2635	2972	53	107	160	213	267
77	4·3315	3662	4015	4374	4737	5107	5483	5864	6252	6646	62	124	186	248	310
78	4·7046	7453	7867	8288	8716	9152	9594	$\bar{0}045$	$\bar{0}504$	$\bar{0}970$	73	146	219	292	365
79	5·1446	1929	2422	2924	3435	3955	4486	5026	5578	6140	87	175	262	350	437
80	5·6713	7297	7894	8502	9124	9758	0405	$\bar{1}066$	$\bar{1}742$	$\bar{2}432$					
81	6·3138	3859	4596	5350	6122	6912	7920	8548	9395	$\bar{0}264$					
82	7·1154	2066	3002	3962	4947	5958	6996	8062	9158	$\bar{0}285$					
83	8·1443	2636	3863	5126	6427	7769	9152	0579	$\bar{2}052$	$\bar{3}572$					
84	9·5144	9·677	9·845	10·02	10·20	10·39	10·58	10·78	10·99	11·20					
85	11·43	11·66	11·91	12·16	12·43	12·71	13·00	13·30	13·62	13·95					
86	14·30	14·67	15·06	15·46	15·89	16·35	16·83	17·34	17·89	18·46					
87	19·08	19·74	20·45	21·20	22·02	22·90	23·86	24·90	26·03	27·27					
88	28·64	30·14	31·82	33·69	35·80	38·19	40·92	44·07	47·74	52·08					
89	57·29	63·66	71·62	81·85	95·49	114·6	143·2	191·0	286·5	573·0					
	0′	6′	12′	18′	24′	30′	36′	42′	48	54′	1	2	3	4	5

Difference columns cease to be useful, owing to the rapidity with which the value of the tangent changes.

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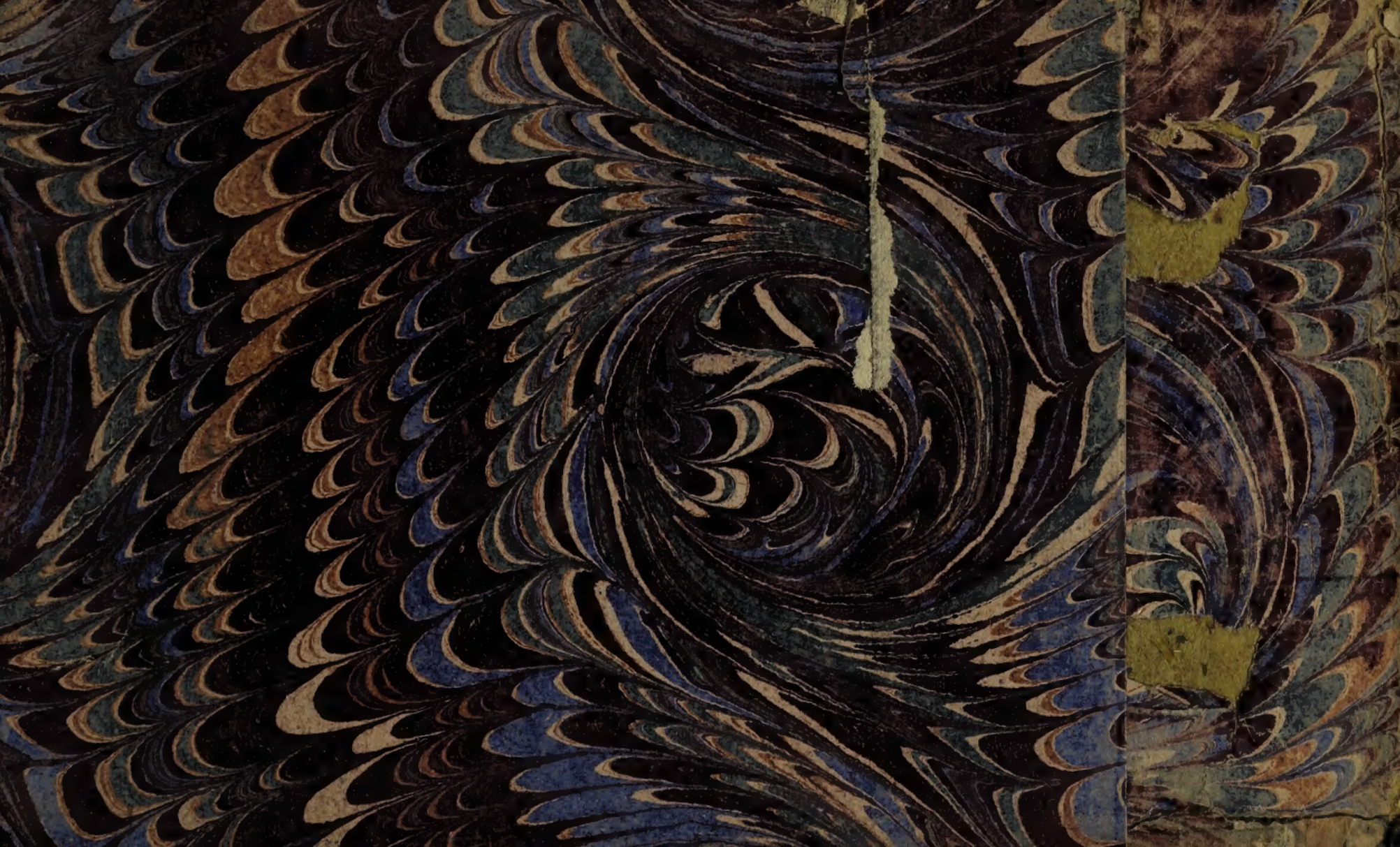

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